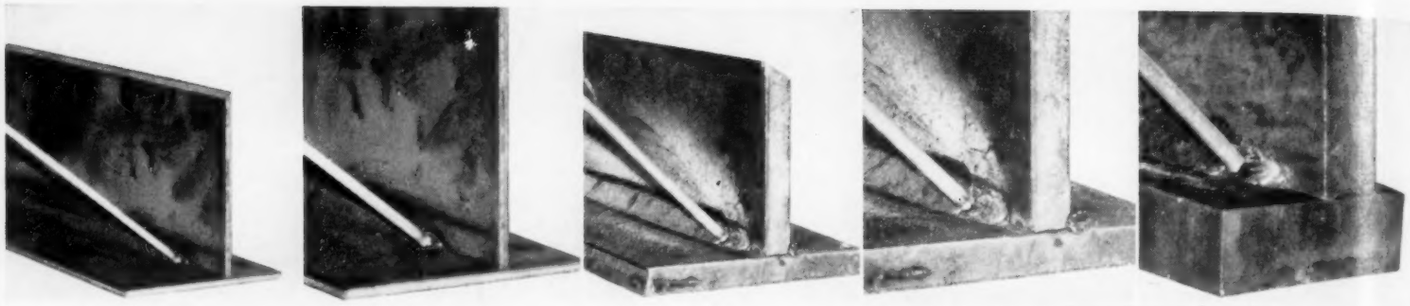
The Welding Journal

JULY, 1938



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The American Welding Society Journal

W. SPRARAGEN, Editor

Published for the Advancement of the Science and Art of Welding

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Welding Journal

VOLUME 17, No. 7 JULY 1938

Designing Welded Piping Systems*

By ARTHUR N. KUGLER†

THE fundamental design considerations for a welded piping system do not materially differ from those for a mechanical joint system. The determinations of pipe size, wall thickness and material are essentially the same for both systems with the exception that in welded assemblies it is unnecessary to employ heavy wall pipe to compensate for threading, grooving or other special preparations for mechanical joints. With the establishment of the operation conditions the selection of pipe material and calculations of pipe sizes and thicknesses is a simple matter.

Required pipe diameters are a function of the volumetric flow and are calculated on this basis. Pipe wall thickness is dependent upon first, pipe diameter, second, upon operating pressure and third the temperature and these three factors should be considered concurrently. For a large majority of systems detailed calculations are unnecessary as the American Society for Testing Materials and the American Standards Association have established minimum pipe thicknesses for the commercial pipe sizes in the standard pressure temperature ranges. The American Society for Testing Materials Designation A106-36 Specification for Pipe for High Temperatures gives detailed data on this phase.

The selection of steel pipe material is again dependent upon service conditions. The American Society for Testing Materials Specification A106-36 recognizes three grades of pipe, namely, Grades A, B & C. Table 1 gives the essential chemical properties of each grade.

* Paper read at AMERICAN WELDING SOCIETY, Evening Lecture Course New York Section—March 15, 1938.

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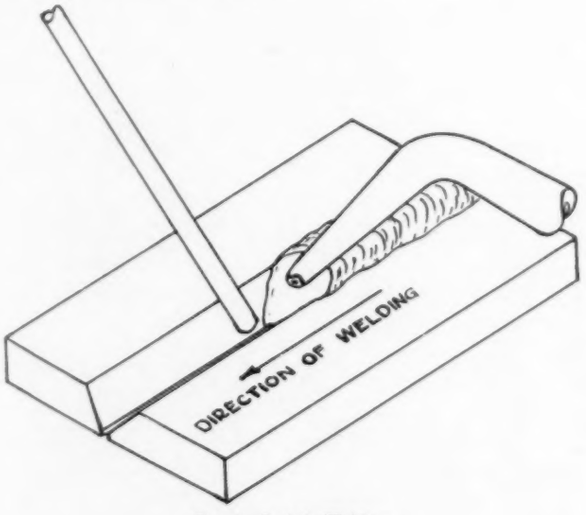


Fig. 1—Puddle Welding

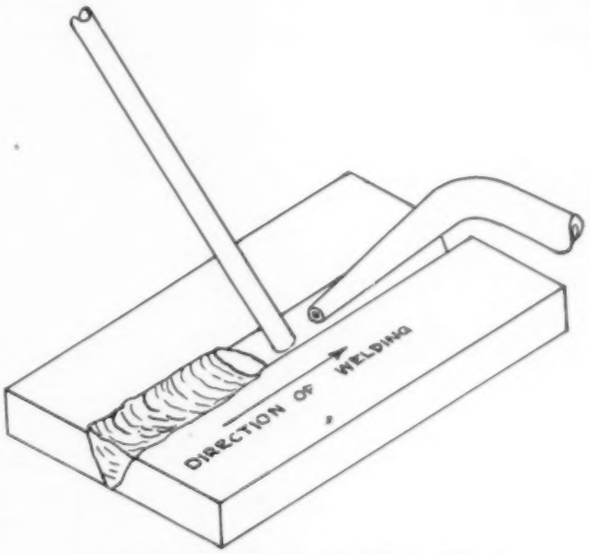


Fig. 2—Backhand or Carburizing Flame Welding

Table 1—Chemical Composition*

	Welded Open-Hearth	Grade A	Seamless Grade B	Grade C
Manganese, %	0.30–0.60	0.30–0.60	0.35–1.50	0.35–1.50
Phosphorus, max., %	0.045	0.04	0.04	0.04
Sulphur, max., %	0.06	0.06	0.06	0.06
Carbon, max., %	..	..	0.40(*a*)	(*a*)

(*a*) In case Grade B or C pipe is to be joined by fusion welding, the purchaser may wish to stipulate the carbon content by special agreement. (See A. S. T. M. A 151).

* Taken from A. S. T. M. A106-36.

Table 2—Physical Properties*

	Welded Open-Hearth	Grade A	Seamless Grade B	Grade C
Tensile strength, psi	45,000	48,000	62,000	75,000
Yield point, psi	25,000	30,000	35,000	45,000
Elongation in 8 in., %	22	..	..	..
Elongation in 2 in., %	..	35	25	20

For transverse tension tests the material shall conform to these minimum tensile requirements except that the elongation in 2 inches shall be 30% for Grade A, 20% for Grade B and 15% for Grade C seamless material.

* Taken from A. S. T. M. A106-36.

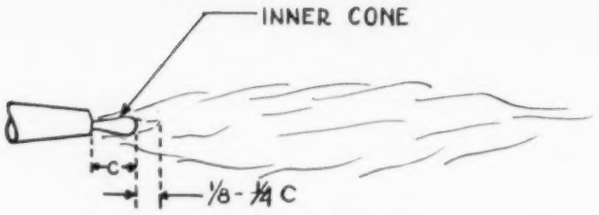


Fig. 3—Carburizing Welding Flame

In Table 2 are the physical properties of these grades. It should be remembered that these grades refer to A. S. T. M. A106-36. Other A. S. T. M. designations also use the term grade with reference to pipe.

Grades A and B are the more common types of pipe encountered and they offer no particular difficulties. Grade C being of higher strength steel, which increased strength is achieved through increased carbon or manganese contents, or both or through the addition of other elements, does offer difficulties in welding. Use of special filler rods and stress relieving or even annealing these welds is necessary on Grade C. Special alloy steel pipes for high pressure, high temperature service in power plants, refineries, chemical plants, etc., are used extensively today but require special welding techniques and heat treatment. This class of pipe is covered by the A. S. T. M. designation A158-36 Seamless Alloy-Steel Pipe for Service at Temperatures from 750–1100° F.

We have indicated in the foregoing that the principal difference in design procedure between welded systems and others is in the joining of the pipe. The ideal piping system would be one that is jointless. Then there would be no opportunities for leaks, expansion and contraction problems would be vastly simplified and insulation costs would be reduced. Mechanical joints with bulky threaded or flanged fittings definitely fail to measure up to this ideal. Welding on the other hand fits this picture practically perfectly—to all intents and purposes welded piping systems are jointless and in effect one continuous pipe.

A more detailed consideration of the advantages of welded piping is in order since it is these factors that have resulted in the wide acceptance of this method of fabrication. Five principal advantages can be enumerated though more could be mentioned. First is the greater simplicity of procedure. This is reflected in the joints, the method of assembly and the means of supporting the pipe. It is fundamental in design procedure that the most direct or simplest design is the best, other factors being equal, therefore welding rates high in this respect. A second element is the increased efficiency. There are no sudden changes in cross-sectional area to increase friction losses. Changes in direction, inevitable in any piping system, are achieved with welding fittings or long sweep bends in such a manner that losses are a minimum. The next factor, weight reduction has a two-fold effect, first on the piping itself and second on the supporting structure. Since in welded piping only that wall thickness necessary to care for the operating conditions is used it follows that the weight of pipe is less than that necessary for systems requiring threading, grooving or other reductions in the pipe wall. The elimination of flanges contributes to a further reduction in pipe weight. A study of Table 3 will indicate the reduction in wall thickness due to threading. As a result of the reduction in pipe weight naturally the hangers and building structure weights are reduced.

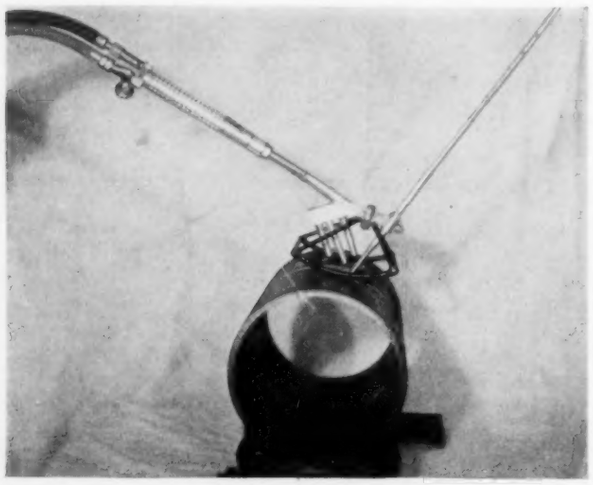


Fig. 4—Multiflame Tip for Pipe Welding

Table 3—Loss by Threading

These tables give the loss of wall-thickness caused by threading both Standard Weight Pipe and Extra-Strong Pipe. Note that the actual effective thickness of a 2-inch Extra-Strong Pipe, after threading, is considerably less than the actual effective thickness of a 2-inch Standard Weight Pipe when welded into the line.

Standard Weight Pipe			Extra Heavy Pipe		
Nominal Pipe Size	Wall Thickness	Per Cent of Wall Removed by Threading	Nominal Pipe Size	Wall Thickness	Per Cent of Wall Removed by Threading
1 in.	0.133 in.	52.6	1 1/4 in.	0.191 in.	36.7
1 1/4	0.140	50.0	1 1/2	0.200	35.0
1 1/2	0.145	48.3	2	0.218	32.1
2	0.154	45.5	2 1/2	0.276	36.2
2 1/2	0.203	49.3	3	0.300	33.3
3	0.216	46.3	3 1/2	0.318	31.5
4	0.237	42.2	4	0.337	29.7
5	0.258	38.8	5	0.375	26.6
6	0.280	35.7	6	0.432	23.1
8	0.322	31.1	8	0.500	20.0
10	0.365	27.5	10	0.500	20.0
12	0.375	26.6	12	0.500	20.0

The next element is the facilitation of insulation or other covering. Since the welded line is free of exterior (and interior too) projections the covering progresses without the difficulties usually encountered at mechanical joints. The final advantage, lowered cost, is really the result of the preceding four. These lessened costs range all the way from about 10% reduction on the smaller sizes of standard weight pipe to as high as 90% on high-pressure high-temperature power piping.

There are two methods generally used to obtain these advantages of welded piping. One is the oxyacetylene procedure, the other the electric arc. Each of these methods will bear further study particularly the various techniques employed as each has some particular advantage.

First, let us consider oxyacetylene welding, more particularly the various methods of depositing weld-metal. Puddle or forehand welding is the older process. In it the torch and rod are so disposed in the vee that the flame points ahead at the unwelded surfaces and at the welding rod which precedes the torch. In manipulation the torch tip and rod are given opposite oscillating movements in semicircular paths to uniformly distribute the heat and the molten metal. See Fig. 1.

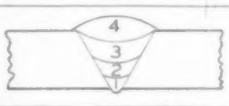
These movements tend to create a large puddle, melting the walls of the vee and consequently giving deep fusion

of the added metal with the base metal. A wide vee, 90° included angle (45° Bevel), is required in this type of welding to permit of the wide movement of torch and rod. Satisfactory welds as determined by standard physical tests can be made with this procedure. However there is great opportunity for having burned metal through the extensive manipulation. Further this exposure to the air tends to create porosity. While good welds are possible, it takes a high degree of skill and constant application to the work to produce them.

Within the last ten years a newer technique has been developed which offers distinct improvements over the older one. Known by such general terms as backhand or carburizing flame welding, it achieves its results from the correlating of several different factors long established. Backhand welding, as such has long been practiced in the standard vee and with a torch and rod manipulation similar to puddle welding. In the new backhand welding the torch and rod are so disposed that the torch flame points back at the completed weld and the rod is interposed between the flame and the weld, Fig. 2. The envelope of the flame completely shields the molten puddle and the white hot rod end.

These positions of torch and rod require less manipulation than in ripple welding and consequently permit the use of narrower vees—60°, that is 30° bevels. This simplification of procedure results in lessened puddling of the filler metal and the base material, in fact a surface

Table 4

RANGE OF PIPE WALL THICKNESS	NUMBER OF LAYERS	METHOD OF DEPOSITING	CROSS SECTION OF WELD
3/8" TO 5/8"	2	TWO LAYERS ONE PASS	
5/8" TO 7/8"	3	THREE LAYERS TWO PASSES 1 & 2 IN ONE PASS LAYER 3 ONE PASS	
7/8" TO 1 1/8"	4	FOUR LAYERS THREE PASSES 1 & 2 IN ONE PASS LAYERS 3 AND 4 IN TWO PASSES	

fusion as indicated on etched specimens, is all that is necessary. The use of smaller vees and the lesser depth of fusion naturally requires less welding rods, oxygen, acetylene and time all of which reflect in lowered welding costs. The simplified technique, exposing the molten puddle less, yields weld-metal of higher quality as evidenced by greater ductility and freedom from porosity.

There is another phase to backhand welding as indicated by the alternative name—carburizing flame welding. Backhand welding can be practiced without the carburizing flame, however in present practice a flame with a light feather of acetylene showing is necessary, Fig. 3. Its use is indicated by the fact that modern gas-welding rods are of low-alloy analyses. In welding with these rods an oxidizing flame is definitely detrimental and to insure against the oxidizing condition, the slight feather of acetylene is recommended.

To sum up for backhand welding it is an oxyacetylene technique which renders the operation relatively simple produces welds of highest physical properties all at lowered costs.

Within the last few years a method welding heavy wall pipe above $^3/_8$ inch thickness has been developed. It is an oxyacetylene welding process in which the weld is deposited in layers rather than one operation, hence the name Multilayer Oxyacetylene Welding. Table 4 shows the recommended number of layers for the various thicknesses. The advantages for this method are a simplification in procedure which results in higher weld quality, lessened material requirements, greater speed and lowered costs. The simplification in procedure is brought about by the fact that the operator is in effect welding relatively thin section with a small puddle which permits him to devote his attention to the peculiar problems of that zone. Obviously the welding proceeds at high rates on these thin layers. The operator, thus freed from the difficulties of controlling a large puddle can, on the first layer, devote his attention to fusing to the bottom of the vee without protrusions on the inside. On subsequent layers he can readily fuse to the side walls and previously deposited metal without fear of breaking through. On the final layer he can secure proper fusion to the upper corners of the beveled ends.

The improvement in weld quality obtained with this method is due first to the simplified technique and second to the heat treatment of previously deposited metal by the subsequent layers. Since the weld-metal is less turbulent and exposed to the air it is denser and of better quality. The raising of the weld-metal underneath above its critical temperature by the welding of the upper layers refines the grain structure and results in higher ductilities without serious reduction in tensile strength.

The reduction in material requirements over those necessary for equivalent single layer welds is due to the fact that carrying a smaller puddle, the operator does not puddle as deeply into the base metal and consequently uses less welding rod and gases and requires less time. A further saving in oxygen, acetylene and time is effected when the first layer seals the bottom of the vee preventing the hot welding gases from escaping in welding the subsequent layers.

The puddle or ripple welding technique can be used in multilayer welding, but obviously the inherent advantages of the backhand procedure make it the preferred method.

Another adaptation of the oxyacetylene procedure is the multiflame tips. While the application of this method is limited to pipe which can be rotated thus placing the welding in the flat or downhand position, its inclusion here is necessary to complete the story on pipe welding. The principal factor in this operation is the specially designed tip and guiding shoe which is attached to a standard welding torch. Figure 4 illustrates one of these tips. The shoe, of welded construction, positions the tip on the pipe so that each flame performs its function. The tube at the front end guides the rod into the vee past the forward tip which preheats the rod. The third tip, at the other end, is provided with two orifices the flames from which impinge on the walls of the vee preheating them. The middle tip performs the actual welding operation. Adjustment of the various tips with respect to the weld and vee is obtained by the curved rods at the bottom of the shoe. Welding progresses at a high rate since both pipe and rod are preheated. A six-inch pipe, for example, is welded in $4^1/_2$ to 5 minutes. A middle western pipe mill using this method on double lengthening pipe has succeeded in trebling their production over that obtained with single flame tips. The weld-metal deposited by this means is of the highest quality since it is deposited under almost ideal conditions and subjected to minimum of working.

For electric welding pipe we have the choice of two procedures. They are the so-called bare electrode welding and shielded arc welding. The term bare electrode is something of a misnomer today as there is very little bare steel wire used for electric welding. These "bare" rods actually have some coating, light as it may be, applied by dipping or as a dust. These light coatings

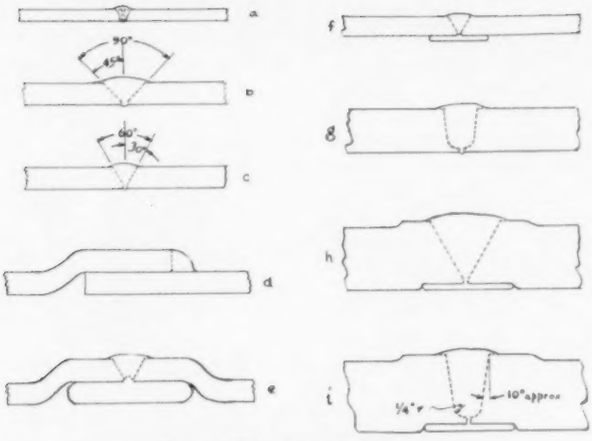


Fig. 5—Welded Pipe Joint Designs

produce a quieter and more readily controlled arc. However, welds made with this class of electrodes will be lacking in physical properties. The tensile strength may be satisfactory, but the ductility will be seriously lacking. This type of welding should not be used on important lines or pipe subjected to high operating stresses. Shielded arc electrodes eliminate these difficulties, perform the welding at higher speeds and produce higher physical results. The shielded arc rods are those with coatings of appreciable thickness which coatings burn in the arc flame producing an inert atmosphere which protects the molten metal from the air. This exclusion of the oxygen and nitrogen of the air results in welds of high strength, excellent ductilities and density. For the important piping, shielded arc electrodes should be used, in fact are the only ones to use to satisfy the requirements of the A. S. A. Code.

Electric welding, unlike oxyacetylene welding, has always employed multiple layers, called beads. A good general rule to follow in determining the number of beads is to allow one for each $^1/_8$ inch of pipe thickness. Thus, for $^1/_4$ inch thick pipe at least two beads should be employed if a back-up strip is used. Without a back-up strip, the three beads are preferable, if the highest quality is desired.

Having considered the various methods of welding, let us now turn to the design of the joint for welding. The simplest joint is made by butting together the square cut ends of the pipe. This should be used only on pipe less than $^3/_{16}$ inch thick, Fig. 5*a*.

For greater thicknesses, the ends should be beveled or grooved as shown in Fig. 5*b*, *c*, *e*, *f*, *g*, *h*, *i*. The old standard joint of 45° bevels, 90° vees is indicated in Fig. 5*b*. This joint is used principally for puddle welding though it can be used for backhand and arc welding. In 5*c* is the type of joint preferred for backhand welding and arc welding. Note the smaller angle of bevel and consequent smaller vee which is conducive of economy. Many pipe mills are still furnishing 45° bevels but will furnish the smaller bevel if requested. Other mills in an effort to standardize on one angle have adopted a compromise half way between 30° and 45°, namely $37^1/_2$°. In some rare instances mills charge extra for any bevel other than 45°. The joint illustrated in Fig. 5*d*, known as the bell and spigot joint, was used several years ago for transmission pipe lines but has been abandoned. Recently it has found acceptance in the oil fields on oil well casing as it offers a ready means of lining up the joints and facilitate welding the pipe in the vertical position. The double bell joint, Fig. 5*e*, is representative of the earliest attempts to provide the back-up strip or liner. The ends of the pipe are expanded an amount equal to the pipe thickness and the chill ring of the same thickness as the pipe is inserted in the bells. A ridge is provided on the internal ring to space the pipe ends and this ridge is fused to the bottom edges of the vee and the weld-metal. This joint was used mostly for arc welding. In this form it is rarely encountered today as the cost of belling the pipe ends and the extra price for the heavy liner make the joints excessively costly. Thinner chill rings, Fig. 5*f*, have supplanted the heavy ones and require no special preparation of the pipe ends. Being thin they do not materially affect the flow through the pipe. These chill rings are of no particular value in oxyacetylene welding but are necessary in arc welding to permit the use of large electrodes and high heats to obtain the greatest welding speed.

In Fig. 5*g* is the U groove employed on heavy wall pipe above $^3/_4$ inch thick. This type of joint can be used with or without a chill ring depending on the other features of the construction. The standard bevelled joint on heavy wall pipe produces such a wide opening at the top, it is difficult to secure a satisfactory weld and further the wide weld is uneconomical. The U groove renders welding simpler and reduces the amount of filler metal necessary, hence this joint is more economical.

Within the last few years the joints illustrated in Fig. 5*h* and *i* have been used extensively. Here the use of the liner is dictated by the necessity of completely eliminating scale and icicles from the pipe interior. Oxide scale or loose metal causes serious damage to the seats of valves, which damage is costly on high pressure and temperature systems. In order not to restrict the flow of high velocity steam these liners are recessed into the pipe wall which has been upset to provide for this thinning.

The design of the lines proper (assuming pipe sizes and weights have been determined) is governed by first the nature of the service and second the method of supporting, i.e., in trenches, in tunnels or conduits, on a structure, or in buildings. Each type of service presents its own problems which require different methods of handling. Thus, in pipe buried underground in trenches the problem of expansion and contraction requires special treatment since conventional expansion loops cannot be employed. On lines up to 12 inches or 14 inches diameter this is handled by placing the line in compression when lowering it. The completed line, supported on skids over the trench is lowered for about 500 feet by removing the skids then a skid is left in place and another section lowered and so on. This is done early in the morning when the pipe is at its shortest length. The lowered sections are backfilled, and then the projecting sections at the skids are crowded into the short section

Fig. 6—Anchor Welded to Line

Fig. 7—Transmission Pipe Line Welding—Roll Welding Pipe Supported on Dollies

Fig. 8—Welded Tunnel Piping Showing Method of Supporting Pipe on Pipe Rollers Hung from Ceiling

Fig. 9—Power Piping Showing Application of Welding Tees, Reducers and Van Stone Flanges

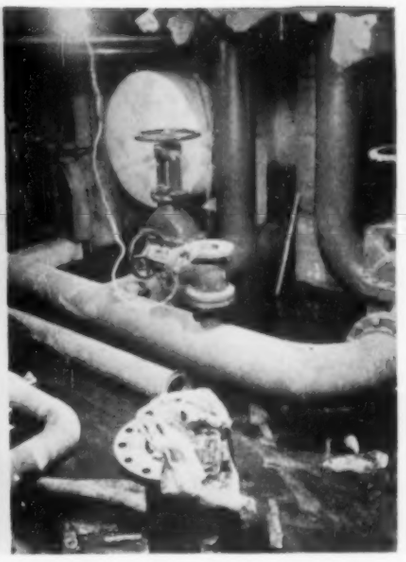


Fig. 10—A Complicated Power Piping Assembly Showing Use of Welding Fittings

of open trench. Thus, the line is in compression and a rise in temperature increases the compression while a drop lessens it. In lowering pipe into a trench care must be exercised not to get any torsion into the pipe as the shear stresses induced are more likely to cause failure than a tension stress due to contraction. On large diameter lines where the size, weight and moment of inertia of the circular cross section are great, the above method is extremely difficult to employ. Consequently, a composite construction is resorted to in which two or three sections of pipe 40 feet long are welded together and these sections are then joined with couplings. These couplings usually permit of slight movement to provide for at least a portion of the temperature movement.

Another form of underground piping is that installed in tunnels or conduits and generally used for conveying steam, hot water and other fluids in which expansion is due rather to internal than external temperature. On such lines the movement due to temperature changes of as much as several hundred degrees Fahrenheit is quite large and must be provided for, either by loops or mechanical expansion joints, if severe stresses in the pipe are to be avoided. On those lines installed in tunnels it is customary to provide expansion chambers in which expansion loops are installed. Obviously this is an expensive means of construction suitable only for large jobs with many lines. On constructions involving but few lines a tile conduit, split in halves, buried in the ground is employed. In this type of work the mechanical expansion joint is ideal. Expansion loops are of two general types—first, those made by bending pipe to large radii, and those assembled from welding elbows and straight lengths of pipe. The former type is the older one, though still used extensively. It is made in a wide variety of shapes to suit conditions. The older assemblies were provided with flanged ends for bolting into lines while today the accepted practice is to weld such loops in the line. The loops fabricated of pipe and welding ells offer many advantages. They can be made to suit dimensional conditions on the job, yet adequately care for the movement, and they are of full pipe thickness throughout.

Pipe carried in tunnels, outdoor structures and buildings may be supported from underneath by pedestals, pipe chairs or stanchions or may be suspended from above by hangers. Whatever the means of support, they should have ample adjustment to permit of positioning on the line when it is hot. Other special supports are necessary at points in lines where peculiar conditions are met. For example, compensating hangers are available which maintain constant support of the pipe through its various movements due to expansion and contraction. Again where lines rise vertically and must be maintained in contact with roller supports at the upper and lower extremities, a spring hanger is employed. Another type of pipe support is that employed to control the direction of movement of a line when expanding. This type of support permits movement in one direction only and prevents the lines from being forced out of its supports.

One phase of welded piping design of utmost importance on lines supported in structures is anchoring. An unanchored line under the stresses of expansion can distort into the most fantastic shapes and nullify otherwise good work. Anchoring lines consists in making a rigid attachment to some immovable base for the purpose of controlling the direction and amount of expansion. Between two fixed points in a pipe we can calculate the expansion and provide therefore by loops. With the ends of the section fixed we know the loops will perform their function. Welding of anchors directly to the pipe is particularly advantageous as it provides a positive connection. Figure 6 illustrates a welded anchor on an outdoor 12-inch steam line.

Changes in direction, branch lines, reductions in size and other deviations from a simple straight line have always been a problem in piping fabrication. Coincident with the growth of welded piping has been the development of welding fittings and today we can secure fittings in a most complete assortment of types, sizes and weights to suit operating conditions. Elbows that reduce friction losses to minimum have long been available and are made of seamless steel or fabricated from flat plate by welding. Similarly seamless tees are on the market in a wide variety of sizes both straight and reducing. For those who prefer to weld a nipple to the main, which has previously been cut to receive it, several types are available which produce both tee and 45° lateral connections. Swedged reducers both concentric and eccentric can be had for reducing from one pipe size to

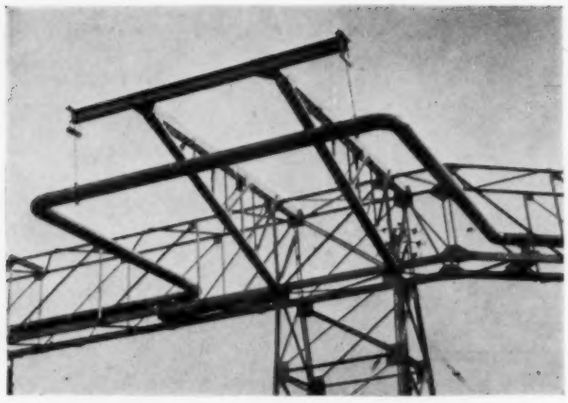


Fig. 11—Expansion Loop Fabricated of Straight Pipe and Welding Elbows. This Line Is Hung from Overhead Structure

another. With all these welding fittings it is possible to assemble fabrications of piping that could not possibly be made up with mechanical joint fittings.

Another means of achieving changes in direction is through pipe bending. Large sizes above say 2 inches are bent hot by experienced pipe benders so there is no buckling or flattening of the pipe walls. Smaller sizes are bent cold with equal success. In fact a contractor knowing how to bend pipe and weld it can install small sizes below 2 inches at costs comparable to those for screw joints.

Still another method of fabricating fittings is available. Tees, miter elbows, reducers and closures can be made from standard sections of pipe with suitable layout templates and the cutting torch. The desired outline is traced on the pipe following the template. Then with the cutting torch the pipe is cut to the lines. The pieces are next fitted together and welded by either process. In employing this method, it is unnecessary to carry a stock of fittings and the various connections can be made with little delay in the field.

Where it is necessary to attach valves, orifices and equipment to welded lines, flanges are necessary. A variety of these fittings are available in the standard designs, to fit the individual needs. The simplest type is the plain slip-on flange which fits over the plain end of the pipe and is attached to it by fillet welds at the outer and inner faces of the flange. This type is used principally on low pressure systems. The high hub welding flange is one specifically designed for welded lines. It is provided with a raised neck or hub which is beveled and attached to the pipe by a simple butt weld. Both these types of flanges require extreme care in positioning so that the bolt holes fall in exactly the correct position. The so-called Van Stone flange eliminates this difficult positioning operation since the flange is loose on a short section of pipe which has been rolled over to provide a shoulder. These shoulders are faced on mating surfaces and the flange merely holds the joint together. The short end of pipe called the Van Stone nipple is beveled for butt welding to the line pipe.

In recent years welding end valves have been manufactured but unfortunately they are available for only the higher pressure conditions and consequently their cost is high. It is to be hoped that we will soon have welding end valves for the lower pressure conditions.

With these many advantages of welded steel pipe, it is natural that the process should be applied to piping of other metals. Among the metals used for welded piping systems we find brass, copper, aluminum, nickel, 18–8 stainless steel and many others. Obviously the welding technique must be one suited to the particular metal employed.

For welding brass pipe the oxyacetylene process is preferred. The filler rod should be one of the bronze-welding rods particularly those of high strength. In designing brass systems never permit the use of dissimilar brasses. Thus, if red brass is desired then the fittings and pipe should be red brass. Any attempt to weld yellow brass pipe to red brass fittings, for example, will lead to difficulties and an unsatisfactory job. Copper pipe and tubing should be welded with the bronze-welding rods and again the fittings should be of the same metal.

Another method of assembling brass and copper pipes has been developed which while not strictly welding involves the use of welding torches in the making of the joint by low temperature brazing. These joints are of the slip type and the cast brass fittings are manufactured with a ring of low temperature brazing alloy in them. In application, it is only necessary to clean and flux both the pipe end and the fitting and assemble them. Then by properly heating first the pipe and then the fitting, the alloy melts and completely fills the annular space. These joints are stronger than either pipe or fitting and can be used in any service for which the piping is satisfactory.

Among the alloy steel pipe being welded, the carbon molybdenum steel pipe is perhaps creating the greatest interest. This steel, referred to earlier, is used for high pressure, high temperature services, particularly in steam power plants. The joint designs employed are those shown in Fig. 5*h* and *i*. The presence of molybdenum in this analysis has the effect of raising the yield strength of the steel at elevated temperatures. Hence, wall thicknesses, thinner than those which would be required for plain carbon steel, can be used with the consequent weight reduction. The method of welding this pipe illustrates the caution which must be exercised when working with alloys which differ materially from the simple analyses usually encountered.

Most all of the carbon molybdenum steel pipe, welded to date, has been welded with the electric arc process, although at present there is research under way which will result in an oxyacetylene rod and procedure. For arc welding the joint is preheated to 300–600° F. and this preheat temperature is automatically maintained during welding which progresses with small beads. On vertical pipe position welds on wall thicknesses of $1^1/_4$ inch–$1^1/_2$ inch, 50 to 60 beads are required. The time for a joint of this type will be 16 to 18 hours. Similarly horizontal pipe position welds require a long time and all are costly. For example, a 10 inch x $1^1/_2$ inch thick horizontal weld will require about 12 hours. The simple rolling welds are generally made in a fabricators shop and are of lower cost than the position weld. After welding, each joint is stress relieved by raising the temperature to 1200° F. and maintaining that temperature in the ratio of 4 hours per inch of thickness. After this the joint is cooled at a rate which must not exceed 250° F. per hour.

We have mentioned earlier that the details governing welded piping design are covered in the American Standards Association Code for Pressure Piping. One phase of this code deserves particularly consideration as it is the subject of much discussion. It is the qualification tests of the welding operators. The code provides for six tests which simulate actual welding conditions on a job. The operators are required to make these test welds in the positions they will encounter on the job.

The first and simplest are the "Fillet Weld" tests made on flat plates. These are made in the flat and

overhead position. The completed sample is broken apart by wedging. The fracture is examined for fusion and foreign inclusions which must not exceed 8 per square inch of fracture exposed. This test is limited to low pressure and low temperature installations.

Along with this simple wedge test a pipe welding test is required for the lower operating conditions. This consists in welding two pieces of pipe in either the horizontal rolling position or the fixed horizontal position depending on the type of welds which will be encountered on the job. From the welded samples four test bars, called coupons are removed. The reinforcement and part of the upper and lower surfaces are removed by machining or grinding. Two of these are subjected to a face bend called the free-bend test and two to the back or root-bend test. The free-bend specimens must show an elongation of 15% minimum as determined by gauge marks set on the weld surface before bending. The root bend test is required to bend 90° without breaking apart. After the above tests the specimens are broken by bending back and forth until fracture occurs. This fracture is then examined for defects as was done with the wedge test of fillet welds and again defects must be less than 8 per square inch of fracture area.

The foregoing tests are for the operators who weld piping operating at low pressures and temperatures. For those who are to weld on systems with higher operating conditions welds are required in rolling, horizontal and vertical positions. Operators who successfully pass higher class tests are not required to pass the lower class tests if the job involves piping in the lower class.

From the test welds, prepared for this highest class test, four test coupons are cut with the oxyacetylene torch. One of these bars is subjected to the reduced section tensile test and required to develop not less than 90% of the minimum specified tensile strength for the pipe material. Another test piece is given the free-bend test and 15% elongation is required. A third test bar is subjected to the back or root bend test and satisfactory specimens must bend 90° without breaking apart. The last coupon is given the nick-break test and the fracture examined. A maximum of six gas pockets per square inch of fracture is permissible provided that no pocket exceeds $^1/_{16}$ inch in any dimension.

The function of these tests is to insure that only qualified welding operators be employed on pipe welding. With this objective there surely can be no quarrel. The difficulties encountered are principally with inexperienced men attempting to pass tests far beyond their ability. It is a wise caution for contractors to submit their prospective candidates to a simple test under the supervision of a serviceman to weed out those who cannot possibly make the grade and coach those who may be weak or out of practice.

Completed piping assemblies can be tested by but few means as destructive tests are out of the question. The two methods most used are the air pressure test and the hydrostatic test. The former is employed principally on low pressure lines, or lines too long to fill with water. A line under air test of 100–150 psi is inspected by applying soap suds to the welds. Leaks are detected by the appearance of bubbles. The hydrostatic test is performed by filling the line with water and pumping up the pressure until it is $1^1/_2$ to 2 times the normal working pressure. While under this pressure the pipe adjacent to each weld is subjected to blows from a 2–5 pound hammer. The blows should be strong enough to jar the pipe but not permanently deform it.

The designing of welded piping systems involves more than the mere specification that, "all piping shall be welded." It requires first, the selection of a suitable pipe material to meet operating requirements that can also be welded and second, the determination of pipe diameters and thicknesses in conformance with operating conditions. Next, the designer should decide on the welding method to be employed which will also include joint designs and heat treatment. Then the expansion and contraction of the lines should be studied along with the provisions, therefore, and this naturally leads to the consideration of fittings. The qualification of operators, testing and inspection of lines should be considered concurrently with the other factors as they are interdependent Obviously the decisions on all these points should be reflected in the final specifications to insure that construction will proceed as planned. Finally and as a further insurance, there should be added a good measure of common sense.

X-Ray of Piping

BY HERBERT R. ISENBURGER†

IN HIS article on Design and Fabrication of High Temperature and High Pressure Piping, published in the June issue of THE WELDING JOURNAL, Mr. Fantz makes a rather broad statement on page 14:

> "The X-ray and other methods of non-destructive testing have not proved practical for piping work, especially on welds made in the field."

It has been our experience that X-ray inspection is not only practical but necessary, particularly for the inspection of field welded joints.

This method has been described by the writer in Mechanical Engineering, November 1937 issue, and is illustrated in the photograph obtained on a recent job.

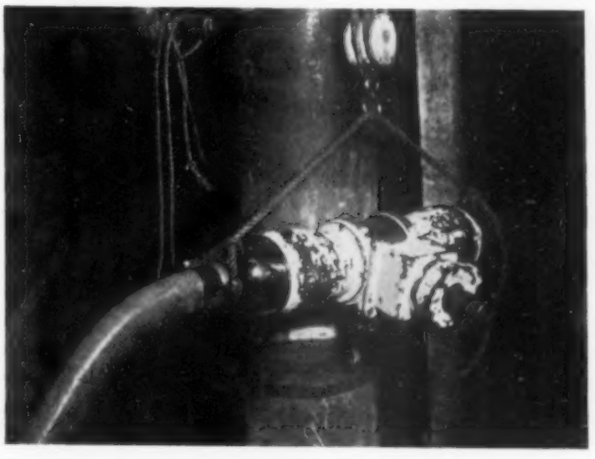


Fig. 1—X-ray Tube Set Up for an Exposure

† St. John X-Ray Service, Inc.

RECOGNIZING AND REPAIRING

Weaknesses in Existing Pressure Vessels*

By K. V. KING† and F. T. PATTON†

EVERY operator of equipment who is interested in safety and avoidance of accidents must periodically take stock of his equipment to assure that no conditions exist which could cause a failure. There are many vessels now in service, even at high pressures and high temperatures, that were built before there was proper appreciation of the importance of keeping the working stresses below a safe minimum in all parts of a vessel. In recent years the improvement of the several codes and rules for the construction of pressure vessels has resulted in safer vessel construction—safer because of better balanced design. However, pressure vessels are for the most part relatively long-lived structures. Hence, no matter how much we have accomplished in improving the new ones, we still have with us vessels embodying the earlier and less exacting features of construction some of which may constitute serious weaknesses. These deficiencies are found in both riveted and welded vessels alike. Unless these are appreciated and corrected, they may persist until some combination of operating conditions causes an unexpected failure.

It is the detection of these inherent weaknesses in vessels and what should be done about them that we want to discuss.

The steps in considering any vessel are briefly: First, to determine where the weaknesses may be in the structure; second, to evaluate the various elements to determine the relative strength of each part; and third, to decide from the relative strength of the various parts whether the allowable working pressure should be reduced, or whether the weak points can be economically altered or strengthened. The available codes and references in the literature outline the principles to follow in strengthening a vessel. It is here also that welding plays its part in making such strengthening possible.

We have been referring to the general problem of appraising the safety of operating equipment. However, it should also be noted that these same principles apply in the case of refitting dismantled, or idle, vessels for further useful service.

* Presented at Western Regional Conference of the AMERICAN WELDING SOCIETY, Los Angeles, March 24, 1938.

† Standard Oil Co. of Calif., San Francisco.

LOCATING WEAKNESSES IN INSPECTION

The importance of a thorough inspection cannot be too strongly emphasized, for many of the existing weaknesses in vessels will only be brought to light by a critical inspection made in appreciation of where these weaknesses are likely to be found in the structure. All too often the practice is to rate existing vessels, or to select second-hand vessels for re-use, on the basis of a cylindrical shell thickness and a joint efficiency. Rating on this simple basis is erroneous for it presumes that no other parts of the vessel will be stressed beyond the allowable stress taken for the shell at its rated pressure. It is because of such assumptions that we have some serious weaknesses in vessels still in use.

Preliminary Considerations

The preliminary step in inspection is to determine the service to which the vessel is subjected, or if idle, its previous service. The features to consider here are:

First: The possibilities of deterioration having occurred from corrosion, caustic embrittlement or oxidation or deformation from direct firing.

Second: The pressures encountered in service: whether peak pressures approaching or even exceeding the rating have occurred, and whether the pressure was steady or pulsating.

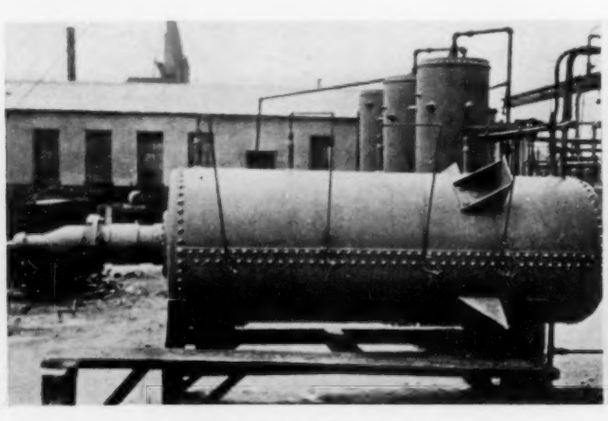


Fig. 1—Typical Flat Head

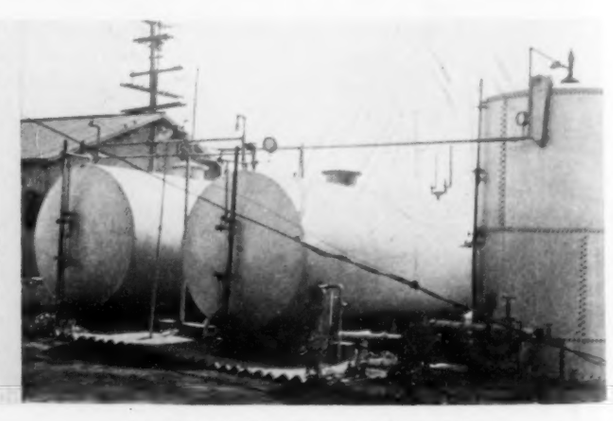


Fig. 2—Typical "No-Knuckle" Dished Heads

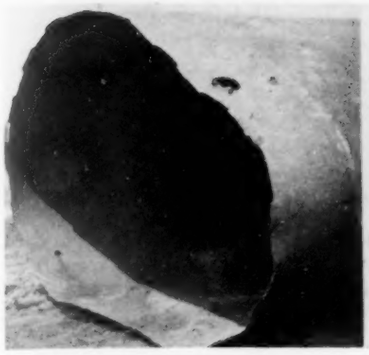


Fig. 3—Failure of "No-Knuckle" Dished Head

Fig. 4—Other End of Vessel Shown in Fig. 3

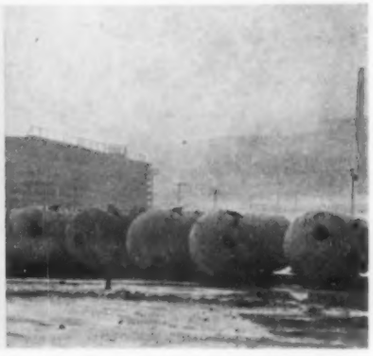


Fig. 5—A Group of Dismantled Vessels Showing Variety of Head Shapes

Third: The conditions of heating and cooling, particularly in heavy shelled vessels operating at high temperatures.

Under certain conditions, the experience with other vessels in entirely similar service may be taken as proof of freedom from corrosion. For instance, freedom from internal corrosion is safe to assume in vessels in an anhydrous ammonia refrigerating system that is properly purged of non-condensible gasses and oil in its operation. Again in natural-gasoline oil absorption plants processing sweet gases (for a limit, say, gas containing less than 0.15 grains H_2S per 100 cu. ft.), it can be safely concluded that the equipment is free from internal corrosion.

Also of importance, preliminary to inspection, is the history of the construction of the vessel. This includes the date it was built, which may give some clue to the type of construction and is particularly important in the case of welded vessels. The initial and subsequent test pressures and what inspection may have been given during manufacture are likewise important. Available drawings of the vessel should be critically examined. If the vessel is of welded construction, it is seldom safe to assume that the joints were actually made as they were detailed on the original design.

From these preliminary considerations, the inspector can form his idea of what may be expected, and the locations in the vessel that should be critically examined. A satisfactory examination almost always involves opening up the vessel for internal inspection. The possible exceptions are those cases where the freedom from corrosion can safely be assumed and all details of internal construction are accurately known.

Details in Inspecting

In the actual inspection, the first consideration is the thickness of the shell and heads. This involves either internal examination or the drilling of gage holes or both. The actual thicknesses of both heads are just as vital as the shell thickness. Where their design is critical, the thicknesses of large nozzle and manway walls is essential.

Riveted shell and head seams will usually be found to conform to the original design details. In vessels that have been in corrosive service, the internal condition of riveted seams must be examined.

The inspection of welded joints involved first determining definitely the method of welding that was used—whether oxyacetylene welded, or electric welded with bare, or with heavy-coated electrodes. The method of preparing the joints for welding, the technique employed in welding and the control of welding quality maintained during the work, and whether or not the welds were stress-relieved should be all ascertained if possible. A careful visual inspection of the welds both on the outside and the inside surfaces is always essential.

If the type of welding or the lack of information concerning the quality of the welds raise any question as to possible lack of penetration, unfused areas, excessive porosity or other internal weld defects, samples should be cut from the welds for physical tests and macroscopic examination.

Where shop facilities can be employed, X-raying is another means of determining the quality of existing welds, particularly in heavy-walled vessels. For vessels in place, although X-raying has been demonstrated as practical, the lack of portable facilities precludes the use of this method.

Unless accurately known, the actual head shape must be determined by taking templets or measuring to determine the radius of the elements. Obvious weaknesses appear in plain dished "no-knuckle" heads and dished heads having relatively sharp knuckle radii or very flat crown shapes. Flat-dished heads raise the question of adequate staying.

In all cases the detail of the head to shell attachment should be determined. In welded construction, the type of welded joint and the proximity of welds to the knuckle of the head are important.

The complete details of all connections to the shell and heads should be determined. Large nozzles and manways should be critically inspected, noting all details of the reinforcement afforded in the attachment. In addition to the shell attachment, the details of nozzle flanges and manheads should be taken. Small connections should be just as carefully examined. In all cases it is important whether or not the nozzle-to-shell welds extend the full depth of the shell and whether the nozzle extends inside the shell.

In addition to these principal elements, the external condition of the shell, the supports for the vessel and exterior structural details should be checked.

DETERMINING RELATIVE STRENGTH OF VESSEL PARTS

With the complete details available, the relative strength of the various elements of the vessel can be determined. Some weaknesses may be readily apparent. Many of the weak elements can be evaluated and will be possible of strengthening by properly designed additions. Some, although not all, unusual features can be evaluated by proof testing. A proof test may often be required before a safe rating can be determined, or even before an estimate for strengthening a vessel can be worked out.

The controlling feature of cylindrical shell sections is usually the longitudinal joint, although occasionally

where vessels have been in corrosive service with the joints protected against attack, areas of the shell may be so thinned as to be the limiting element. Riveted shell joints are evaluated by conventional methods.

Welded Joints

Evaluation of welded shell joints can be based upon the following principles:

Good, sound, ductile, acetylene welds of unknown origin can be safely ascribed a 70% efficiency.

Welds obviously made with bare electrodes can be allowed a 50% efficiency if the samples show them to be relatively sound, and if they are not in locations subject to undue bending; otherwise they should be condemned.

Sound welds made with a coated electrode and oxy-acetylene welds of known quality should be allowed the efficiencies established in the A. P. I.-A. S. M. E. joint code.

Forged welds are allowed a 70% efficiency, unless there is reason to suspect the quality of the work.

In all cases where dealing with shell plates and welds, the construction factors given in the A. P. I.-A. S. M. E. code for the different grades of plate material should be taken into account. Unless a Class A or Class B material is known to have been used, the Class C factor of 0.92 should be employed.

Heads

In determining the safe pressure rating for a vessel head, the most rational method is that given in the A. P. I.-A. S. M. E. code. By this method, the rated pressure is based upon the actual stress existing in the most stressed portion as determined from the measured shape of the head.

Flat heads can also be evaluated according to the A. P. I.-A. S. M. E. or A. S. M. E. code rules, if the attachment to the shell is a design recognized in these references as permissible. Where flat heads, particularly light plate heads, are attached by fillet welds, there is no ready method for computing the intensity of the bending stresses set up in the welds. Such construction must be condemned as unreliable for any pressure causing deflection of the head.

Plain-dished or "no-knuckle" heads are another inherently weak construction. Their weakness lies in the high stresses occasioned in the head-to-shell welds by the sharp change in contour at this point. The inability to fit large heads of this type accurately in a cylindrical shell precludes the possibility of a 100% sound weld of uniform section. In one case where relatively thick-dished heads are inserted inside small diameter shells and welded to the shell for the full depth of the head, they can be computed. Aside from this, plain-dished heads should be condemned as indeterminate and unreliable. Where these heads are subject to fluctuating pressures or pulsation, they constitute a serious hazard. A disastrous failure of a head of this type in an 8-foot diameter vessel operating under low but pulsating internal pressures occurred a few years ago on the Pacific Coast.

Figure 1 illustrates a typical flat head which can be calculated by the code rules, using the known thickness to solve for the safe working pressure. The resulting safe pressure will be low. For the 30-inch diameter 1/2-inch shell vessel shows it is only 15 pounds per square inch. In order to realize the useful shell strength of such a vessel, the heads must be adequately stayed.

Figure 2 shows two typical "no-knuckle" dished heads in pressure tanks. In one case the head is attached by a single butt weld. In the other tank the end of the shell is crimped over the head and fillet welded. Figure 3 shows a complete failure of a "no-knuckle" dished head. Compared to the loss which resulted for this failure, the cost of proper construction, or even of replacing the heads, would have been insignificant. Figure 4 shows the other end of this vessel illustrating the typical construction. Not only was this design poor, but the fitting up and the quality of the weld were both of inferior quality.

Figure 5 shows a number of dismantled vessels which, although similar in general dimensions, differed in their shell connections, head shape and shell thickness. Each one presented its particular set of problems in altering and strengthening for re-use. All of these vessels have been converted for useful service at considerable savings over the cost of new vessels.

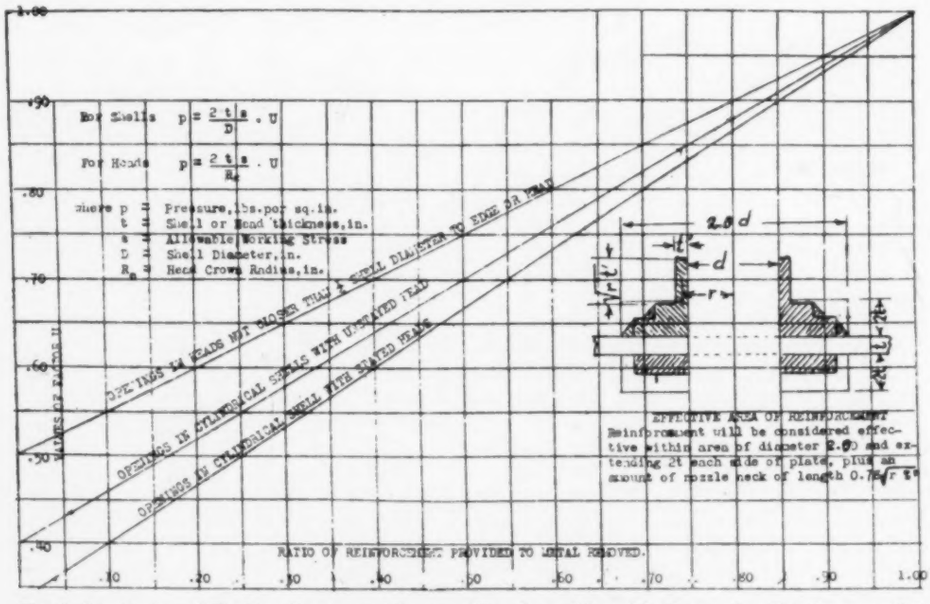
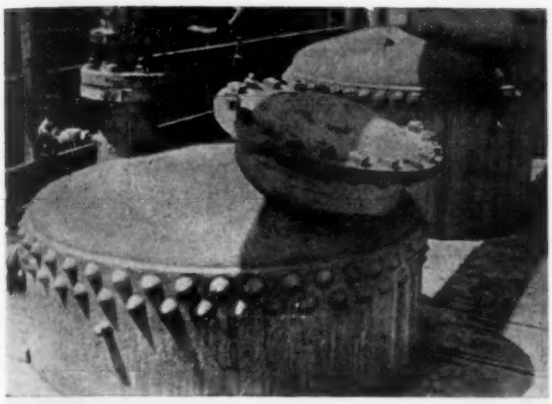

For Shells p = 2 t s / D . U
For Heads p = 2 t s / R_c . U
Where p = Pressure, lbs. per sq. in.
t = Shell or Head thickness, in.
s = Allowable Working Stress
D = Shell Diameter, in.
R_c = Head Crown Radius, in.
VALUES OF FACTOR U
OPENINGS IN HEADS NOT CLOSER THAN ½ SHELL DIAMETER TO EDGE OR SEAM
OPENINGS IN CYLINDRICAL SHELLS WITH UNSTAYED SEAM
OPENINGS IN CYLINDRICAL SHELL WITH STAYED SEAM
RATIO OF REINFORCEMENT PROVIDED TO METAL REMOVED.
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
2.5 d
EFFECTIVE AREA OF REINFORCEMENT
Reinforcement will be considered effective within area of diameter 2.5D and extending 2t each side of plate, plus an amount of nozzle neck of length 0.7√r t

Fig. 6—Limitation of Working Pressure of Pressure Vessels as Affected by Incomplete Reinforcement of Openings



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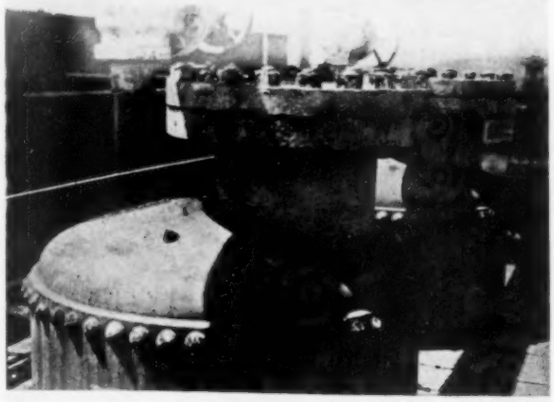

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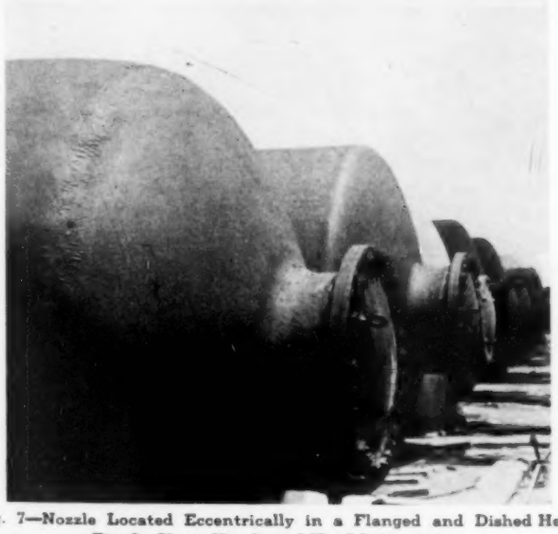

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Fig. 7—Nozzle Located Eccentrically in a Flanged and Dished Head
Fig. 8—Sharp Nozzle and Head Intersection
Fig. 9—Deformation of Head of First Vessel Under Excessive Internal Pressure

Nozzles and Connections

The evaluation of the strength of existing openings presents one of the most troublesome problems. The design methods given in the A. P. I.-A. S. M. E. and A. S. M. E. codes are not applicable for evaluating the safe rating of existing openings. A method which can be applied directly was developed by Mr. F. L. Maker in the early work in preparation of the A. P. I.-A. S. M. E. code. This method determines an efficiency for a partially reinforced opening on the basis of the increased stress which it occasions in the vessel shell or head. This has for its background the developments which show that in the case of a circular hole in a stretched plate, the maximum stress which occurs at the edge of the opening is: (1) 2.5 times the stress in the plate where the stress across the hole in one direction is twice that in the direction at 90 degrees—that being the loading occurring in a cylindrical shell; and (2) two times the stress in the plate where the stress across the hole is equal in all directions—this being the loading in a spherical shell. As long as openings in shells and heads are not too large, relative to the diameter, and are symmetrically located in heads, these increases of stress determined for flat plates will apply with negligible error to cylindrical shells and spherical heads.

The chart Fig. 6 shows a linear relation between ratio of reinforcement and a reinforcement efficiency factor U. The ratio of reinforcement is determined by the ratio of the cross section of added metal and nozzle wall that is effective as reinforcing, to the cross section area of shell removed in the opening. The area within which added reinforcing is effective is shown on the chart. The width of this area is twice the width of the opening. The height of nozzle that can be considered effective as reinforcing is taken as $0.78\sqrt{rt}$ (r being the mean radius of the nozzle and t the nozzle thickness). This height is measured above the shell or added reinforcing ring.

From this, it can be seen that an unreinforced hole in a shell such as a threaded opening tapped directly in the plate would offer no reinforcement and would have the same limiting effect as a 40% longitudinal joint. Where the metal removed is entirely replaced by effective reinforcing, the opening can be considered as strong as the seamless shell. It follows that when the U factor exceeds the shell-joint efficiency, the latter becomes the limiting consideration.

All openings regardless of size should be considered. A small opening occasions just as high stresses at the hole as a large one. The worst cases are the totally unreinforced openings such as tapped holes in a shell that is stressed up to its allowable limit. Cracks developing from such openings are not uncommon. The fact that there are not more failures resulting is undoubtedly due to the facts that shells are generally operated at relatively low stresses so that they have some thickness effective as reinforcing, and also that when stresses in a ductile material exceed the yield point, the metal will deform and relieve the peak stress.

Nozzle, manway necks and their flanges and cover plates are seldom serious weaknesses in themselves. Cast-iron flanges screwed on nozzles should be safe for their pressure-temperature ratings, although they are not reliable for shock conditions, or in case of fire. Light "slip-on" or "built-up" types of welded flanges may be serious weaknesses, particularly as bending of the flange induces high stresses in the weld to the nozzle or manway neck. Light steel manway covers, unless extremely underproportioned, may be weak but still not serious hazards, for their deflection under pressure will cause leakage before there is any danger of rupture.

Supports, shell brackets and other attachments may also require a check, and the effects of their reactions on the shell must be considered where they increase the loading.

There are often features of construction which cannot be as readily evaluated as the above, and there are some which cannot be given any safe pressure rating.

Indeterminate Features

Typical indeterminate features are badly deformed shells and heads, distorted negative heads, openings in the knuckle area of heads and unusually light manway flanges and covers. Most of these can be evaluated by proof testing.

Definitely unsafe elements are large "no-knuckle"

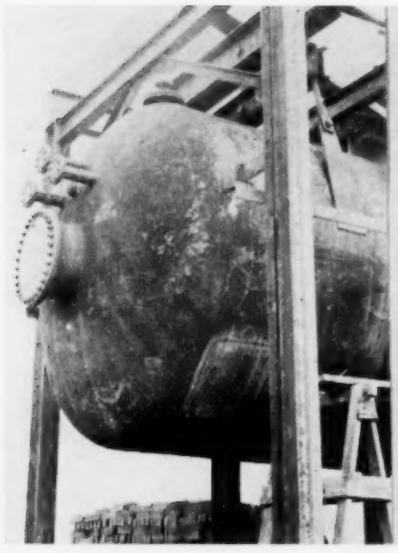


Fig. 10—Rectangular Flush Patch in Shell to Eliminate Two Openings

Fig. 11—Close-Up View of Patch Shown in Fig. 10

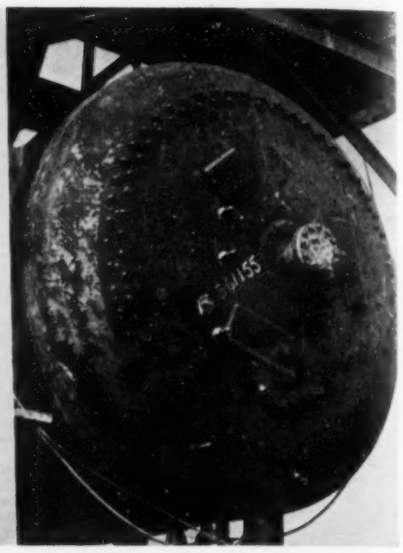


Fig. 12—Repair in Head Overcome Serious Corrosion

heads, flat heads attached by fillet welds and cast-iron riveted nozzles or manway frames. Such elements cannot be allowed any safe pressure rating.

Proof testing has some value in determining the rating of incalculable elements although it is by no means positive in all cases. To obtain definite indications of first yield, the surfaces must be thoroughly cleaned of paint and the brittle coat used (lime wash or Plaster of Paris) must be carefully applied. Where there are sharp intersections as where cylindrical nozzles are welded into shells or heads, the highly stressed areas may not yield sufficiently, or over sufficient area, to give an indication by flaking of the brittle coat. Then, too, if the vessel was given a high initial test which may have exceeded the yield point of some elements, the proof test must be carried to a still higher pressure, if it is to cause further deformation at these points.

Figure 7 illustrates a type of nozzle located eccentrically in a flanged and dished head so that it intersects the knuckle area. The stresses around such an opening cannot be exactly evaluated but a proof test is feasible because of the flared out shape of the manway opening. In an actual test on a similar vessel a very good indication of first yield showed in the knuckle area adjacent to the manway opening.

Figure 8 shows a sharp nozzle and head intersection where the indication of yield in a proof test cannot be depended upon.

Figure 9 shows how a head deforms under excessive internal pressure. The vessel in the foreground had a head shape identical with those beyond it. The vessel was tested to rupture. Yielding of the head around the knuckle and manway started at a low pressure and as the head deformed it tended toward the stronger elliptical shape. The vessel finally failed in the shell plate.

REPAIRING WEAK PARTS OF VESSELS

With all elements of the vessel considered and the relative strength of each part evaluated, the seriousness of the limitations imposed by any weaknesses will determine whether a vessel should be rerated for a lower working pressure or altered by strengthening or replacing highly stressed or questionable parts.

Welding offers an economical means of strengthening or replacing weak elements of vessels. However, because of its wide range of application, there are occasions where welded repairs are made without due consideration of design, or of the stresses set up in the welding, with the result that the original weakness may be intensified. Welding is too useful a method to be allowed to suffer from abuses of this kind. Also, it must be recognized that there are occasionally repairs or replacements where riveted work is more practical and economical than welding.

Shell Patches

One of the commonest requirements for patching is where a defective shell or head section is removed or where an unused opening is eliminated. In such cases, it is entirely possible to install a satisfactory patch by welding although some care must be exercised in fitting up and in minimizing the shrinkage stresses. Such patches can be either lapped or inserted and butt welded, as long as the patch is equivalent in strength to the longitudinal shell joint. Although such work has been done by oxyacetylene welding, electric-arc welding which causes far less heating of the shell is the preferable method. Even so, in installing flush patches peening the weld is necessary to relieve the shrinkage strains and in plate over $^{5}/_{8}$-in. in thickness, a thermal stress relief should be given after the welding. Flush patches can be installed intersecting riveted joints, with seal welding of the straps and rivets either side of the patch.

Figure 10 shows the location of a rectangular flush patch installed in a vessel shell to eliminate two unreinforced openings that were not needed. Figure 11 following shows the detail of this patch.

Figure 12 shows a repair made in place to a flanged and dished head which was seriously corroded in the center of the crown section. In this instance a new crown section was installed using countersunk head-patch bolts and keeping this lapped joint well out of the knuckle area. The bolts and lapped edge were seal welded inside.

Figure 13 shows a flush patch fitted and welded in an old manway opening. In this case the patch was made in the vessel shell, leaving the manway flange ring and rivets in place, rather than attempting the larger patch that would be necessary to go outside the rivet hole circle.

Shell Joints

Repairs to defective sections of shell joints can be accomplished by welding even on relatively heavy shelled vessels. Here again the important consideration is to minimize the stresses set up by shrinkage. This can be done through proper preparation for the weld and by careful procedure in making the weld—building up with single beads rather than layers, stopping the welding to minimize the heating and peening the metal as deposited.

It is often necessary to replace welded seams made with bare electrodes or other poor quality welding. There is no method of strengthening such welds other than by completely rewelding the seam. The alternative, often proposed, of applying a welded outside butt strap over a weld does not strengthen the main weld and only results in the lap-welded patch, which is not a desirable type of joint, taking most of the load. It is possible in some cases to preserve the alignment by chipping out over half the depth of a defective weld, rewelding and then chipping out the other half and completing the new weld.

Heads

Where the weakness in a vessel is caused by a poor head shape, there is little that can be done to strengthen a head short of complete replacement with a new head, or heads, of adequate design. Where the weakness is due to a very flat crown and the knuckle radius is well formed, a reasonable design for staying the crown of the head can be developed and installed by welding. There have been attempts to brace such heads by fitting beams across the head in a symmetrical pattern and carrying the load down to welded attachments to the shell but such procedure cannot be endorsed. Attempts to strengthen "no-knuckle" or plain dished heads by welding clips or brackets across the head to shell seam should never be undertaken. In view of the lack of dependability of the plain dished head, no alternatives short of replacement should ever be entertained.

Reinforcing Nozzles and Connections

Relatively small corroded areas, or corroded patches inside nozzles and connections can be built up by arc depositing metal, applying the metal in single parallel beads and peening each bead as laid in. Obviously, even this method has its limitations as to the amount of welding that can be attempted in any one location without setting up dangerous stresses in the parent plate.

In laying out reinforcing for openings, there are a number of principles which should always be considered. These are:

Any reinforcing metal added should be placed close in around the opening. Balancing the addition between inside and outside is preferable to making the entire addition outside the shell or head.

Welds of nozzles to shell and of reinforcing rings to nozzle necks should always be welded the full depth of the plate. Likewise welds around pads or around nozzles having integral reinforcing flanges applied to a shell or head should be full fillet welds.

Any added reinforcing should be closely fitted to insure that it will act with the element reinforced and thereby avoid local overstressing in the connection.

Judgment should be used in determining the size of fillet welds for reinforcing and the relative thickness of built-up pads considering the thickness of the shell to which they are to be applied, and the stresses set up in the shell from the welding. At the same time the attachment welds must be proportioned to carry the loading from the shell to the pad or nozzle.

Initial consideration should be given to the percentage reinforcement that is justified. This involves the other limiting elements, the service conditions and the likelihood of reuse of the vessel in other service. In some cases full reinforcing may result in high localized stresses from the welding; whereas a partial reinforcement providing strength equal to some other limiting feature may be all that is needed and can be applied with a reasonable amount of welding.

Unreinforced tapped holes are often weaknesses. In light shells welding in a pipe coupling or welding on a boiler flange, "Bonney" flange or "Thredolet" offers an easy means of reinforcing the plain, tapped hole. In heavy shells it is usually preferable to build up a welded pad. Where cracks are found at a tapped hole, the defect should be entirely cut out and welded up and the necessary reinforcing added as well.

Small threaded openings located in the knuckle of a head—a common location for gage glass openings should be welded closed and the connection relocated in a less highly stressed area.

Existing boiler flanges and "Bonney" flanges are often found welded on the outside only, a weakness which can be corrected by adding an additional fillet weld to the shells inside. Where they are added they should always be welded both inside and outside.

Pipe nozzles welded directly into shells and heads are common. Before attempting any reinforcing it is wise to examine the nozzle-to-shell weld. If this proves to be simply an outside fillet weld, it must be remade.

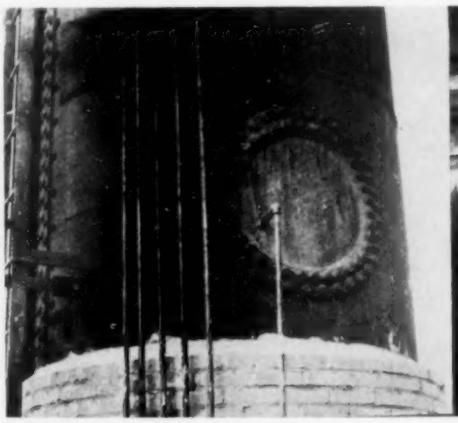


Fig. 13—Flush Patch in Old Manway Opening

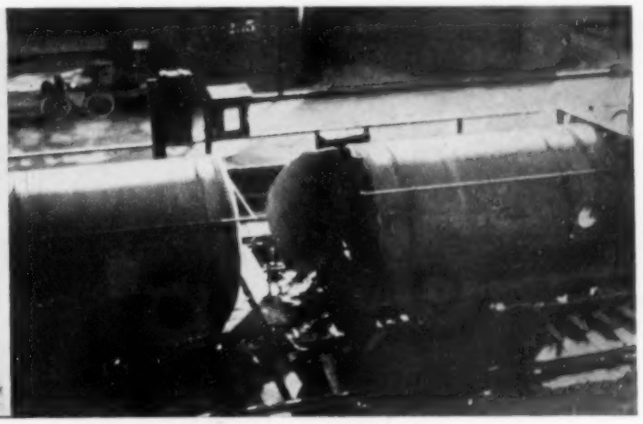


Fig. 14—Failure in Head of a Riveted Pressure Car Tank

Where the nozzle itself is sound, the conventional plate reinforcing ring can be applied, in one or two pieces. It is obvious that the welded joints in rings and in nozzle walls should be oriented across the axis of a cylindrical shell. Flared out reinforcing rings similar to pipe reinforcing saddles are usually less effective reinforcing than flat rings. The saddles seldom fit accurately around an opening, and they lack the attachment welding close around the base of the nozzle obtainable with the flat ring. Where the nozzle opening itself is flared out, either a saddle ring or a flat ring can be used, but the saddle ring should be carefully fitted and preferably plug-welded around the opening to transmit the loading to the ring.

Inadequately reinforced nozzles present varying problems. Often in riveted nozzles the rivet shear strength is deficient and can be strengthened by a fillet weld around the pad. Again the riveted reinforcing flange may be too light and can be strengthened by cutting out the rivets and adding an internal reinforcing ring, and redriving the rivets.

The most troublesome connections to reinforce are those which are located in the knuckle area of dished heads. If an alteration is of such consequence as to involve stress relief and X-ray examination such connections should be patched and relocated. Otherwise the reinforcing must be carefully proportioned to minimize localized stresses both from the welding and from service. Unless a vessel represents a large investment, reinforcing such openings can seldom be justified. The only alternatives are, of course, a new head, or a reduced rating, or determination of its strength by a proof test.

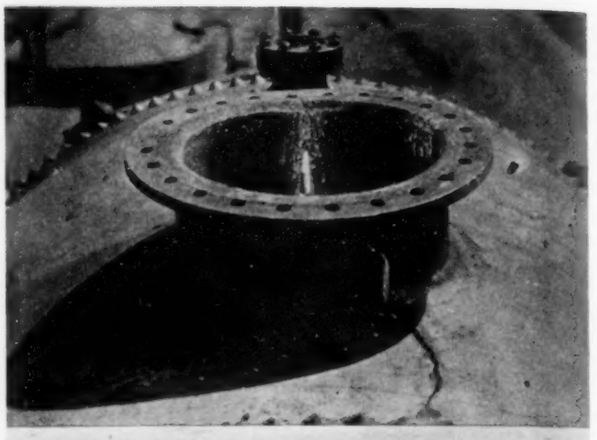
Elliptical flanged-in manholes of the integral type are weaknesses, particularly when located eccentrically in a vessel head. Where these occur in a head knuckle area or so close to this area that an added reinforcing ring would extend into it, strengthening should not be attempted. Their safe rating can be determined by a proof test and this will be found to be relatively low.

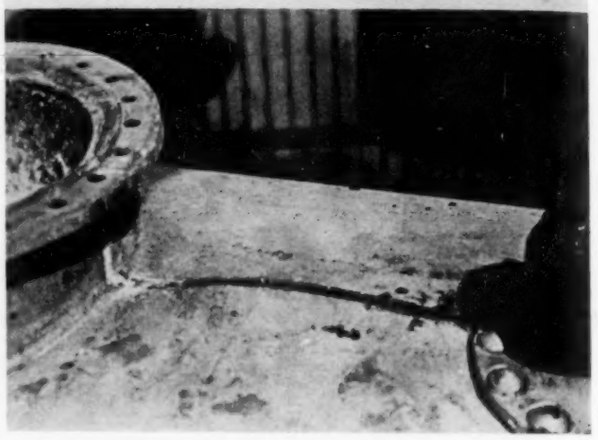
In less highly stressed locations such openings can be reinforced by the addition of welded or riveted rings. It is preferable, however, to cut out the integral flanging and install a ring around the opening which itself carries the seating surface, or even to replace with a symmetrical round flanged manway neck.

TYPICAL FAILURES

Because of poor shape and incomplete reinforcement, heads and openings may be relatively weak and still not be stressed to the point of failure at the working pressure of the shell. This is usually the case, and as a result these features do not make themselves known by failing. What we often have is a shell operating with a real factor of safety of 4 or 5 and heads and openings that actually have safety factors of on the order of 2 to 3. Such vessels do not have the reserve to withstand the over-pressure that the assumed nominal safety factor and allowable design stress would indicate. Also the initial test pressure is not always a real criterion of the strength of the vessel after it has been in service for a considerable period.

As illustrations, we have two actual cases where such weak elements failed under a pressure which did not even stress the shell to its yield point, indicating that the actual factor of safety was less than half of that afforded in the shell joint.





Figs. 16 and 17—Failure of a Riveted Vessel at an Inadequately Reinforced Welded Connection

Figure 14 shows the failure of the head in a riveted pressure car tank. In this instance the head ruptured in the knuckle area. The head was flanged to a relatively sharp radius and the crown radius was relatively large.

Figure 17 shows a failure of a riveted vessel shell which developed at an inadequately reinforced welded connection. The fact that the seam in the manway neck was located on the axis of the shell acted to reduce the effectiveness of the slight reinforcing afforded by the neck and the fillet weld to the shell. Figure 16 shows the break on the other side of the manway ending at the properly reinforced riveted nozzle. In this instance, the light welded manway was substituted for a completely reinforced design to effect a slight saving in the initial cost of the vessel.

CONCLUSIONS

In these remarks we have tried to stress basic principles rather than specific construction code requirements, and we have paid particular attention to the major weaknesses, inherent in seams, heads and openings. If these can be generally appreciated and the unsatisfactory conditions will be corrected, we will be well on our way toward realizing a uniform standard for safety in existing pressure vessels.

OPERATOR'S OUTLINE OF WELDED Casing Requirements*

By K. N. SAATJIAN† and WALTER MAIN‡

WELDED surface casings are not new in the oil fields. Welded water and oil strings, however, are comparatively recent developments. This paper is intended to present the oil operator's viewpoint on the latter application.

It was thought by your Program Committee that a frank discussion of the merits and the limitations, of both the welded and the conventional type threaded and coupled joints, as we know them today, might clear up some misconceptions for or against either method.

Too much cannot be said of the remarkable strides made during the last decade in welding technique, welding material and equipment, which proved to be such a boon to the structural steel fabricator, the pressure vessel manufacturer, and the machine designer. It is possible, however, that further improvements are necessary to meet more adequate by the conditions peculiar to one of the most difficult tasks of an oil operator: successful setting of a water or an oil string.

Some of the important factors affecting the casing joints are discussed here briefly.

TENSILE STRENGTH

Welded joints in general, when properly made, are stronger in tension than most threaded and coupled joints. They possess greater "joint efficiency." The efficiency in tension, of the A.P.I. type of threaded and coupled casing joint, ranges from 35% on larger sizes, to about 80% on smaller sizes. Joint efficiencies approaching 100% are obtainable only in upset type pipe. Welded joints of the bell and spigot, double bell and sleeve type, on the other hand, are capable of producing a minimum joint efficiency of 60%; while plain butt joints have given efficiencies as high as 100%. In his paper, "Circumferential Field Welding of Casing," presented at the November 1937, meeting of the A.P.I. in Chicago, Mr. L. R. Hodell reports that, to his surprise, the joint efficiencies of the plain butt-welded joints fell below the bell and spigot type. Regardless of which type has the higher efficiency, the fact remains that in this respect, welded joint is well ahead of the ordinary threaded and coupled joint.

There has always been some controversy over the need for high efficiencies in casing joints. It goes without saying, however, that stronger joints, within the yield-point of the steel in the body of pipe, are to be preferred, if obtainable economically.

Neither should the fact be overlooked, that in the majority of cases, the depth to which a string of casing can be safely set is controlled by its collapse rating, and that joint efficiencies, as low as 35%, will permit the setting of large size casings to greater depths than feasible from standpoint of collapse. However, possibility of bending in the well, and other uncontrollable stresses imposed on the pipe, make it advisable to provide for stronger joints in tension. In other words, in spite of the fact that large diameter casings have relatively high strength in tension and low rating in collapse, there still are very valid reasons in favor of increased joint efficiencies; and from this point of view, welded casing joints certainly have the advantage over the threaded and coupled joints in the larger sizes ($10^3/_4$ inches and larger), and also in smaller sizes where the $\frac{t}{D}$ ratio is less than 0.035.

TIGHTNESS OF JOINT

There is very little likelihood of a welded joint not being hydrostatically tight, if properly done. Of the many welded casing joints we have witnessed and examined, very few indeed ever showed evidence of leaking. When welded casing was relatively new, leakage occurred through the "plug" or "rivet" welds; that is, welds made through round holes drilled through the belled ends of the pipe. This practice has long since fallen into disuse and should not now enter into this discussion.

Two years ago there were many instances of leaky threaded and coupled casing strings, but recent improvements in threads, and closer control of tolerances have materially reduced leakage. It is perhaps too much, to expect that all difficulties with threaded connections will be completely eliminated. It can be stated in all fairness, however, that the A.P.I. type threaded and coupled joints are fast approaching the leak-proof status of welded connections. In fact, leakage in threaded and coupled pipe at reasonable pressures can now be traced almost entirely, to lack of adequate inspection and lack of care in making up the joints. Some of the special type threaded and coupled joints with upset ends, have the reputation of being even more reliably leak-proof.

In the matter of hydrostatic tightness, particularly in high-pressure service, welded joints offer a decided advantage over the threaded connections.

CASING MATERIALS

Practically all casings conform to A.P.I. Grade "C" or Grade "D" material in physical properties. High physical properties of Grade "D" steel, with respect to collapse and tension, adapt it for longer strings. At the present state of development, however, no adequate and practical means has as yet been devised to weld, for casing purposes, Grade "D" material, or any other steel having in excess of 0.35% carbon. And, although there is no "carbon" requirement for A.P.I. Grade "C" steel, it is understood that the general run of Grade "C" material contains the maximum permissible carbon content from standpoint of weldability.

* Presented at Western Regional Conference, AMERICAN WELDING SOCIETY, Los Angeles, Calif., March 21, 1938.

† The Texas Company.
‡ Youngstown Sheet & Tube Company.

There are certain so-called "light alloy" and "high-yield" casing steels now available, having better welding and higher physical properties than Grade "C". The application of such steels will be covered more in detail in a paper to be presented by Messrs. J. C. Hodge and C. R. Sadler of the Babcock and Wilcox Company. It is apparent, however, that there is some limitation for welded joints, from standpoint of chemical analysis; while no such limitation exists for threaded and coupled connections.

RELIABILITY

There are certain defects that occur in threading a coupled casing joint, not readily discernible with the naked eye, which might impair its tensile strength or hydrostatic tightness. These defects, for the most part, lend themselves to mechanical measurement. They include errors in taper, pitch, thread form (including height), thread alignment, pitch diameter and the like, as well as battered and damaged threads. With modern inspection methods and precision tools these defects are readily brought to light, and since inspection can be made long before the casing is needed for the well, there is little excuse for holding up a casing job to look for defects. Furthermore, inspections can be repeated a great number of times before the casing is run. These facts tend to reduce the human element, or the element of error, to a minimum.

With welded casing joints, in spite of the qualification of the welder, there is always that element of doubt, that the welder might not have obtained as complete penetration as he thought he did; that he might have left porous places, blow-holes, slag and other defective spots in the weld; that an unnoticed movement of the pipe during welding caused a crack to start; or, perhaps the cooling conditions were too severe, and for that reason shrinkage strains occurred which, when added to bending or severe tensile stresses in service, might cause a fracture.

It is quite feasible, of course, to make a pretty thorough examination of the outer surface of each weld-bead for checks, cracks and other evidences of defects, but those which are hidden beneath the surface, and particularly the lack of penetration at the innermost point of the weld, can rarely be detected by visual inspection.

The welding contractors, specializing in this class of work, in general are highly reliable. They employ very high standards in training and selecting their welding crews. They are equally careful in the selection of electrodes and maintenance of welding equipment; nevertheless, it is still necessary to make periodical test inspection by completely removing a joint at the well, which entails loss of time, and the complete results of inspection cannot be made available immediately.

Taken all-in-all, at the present, it appears that there is less element of uncertainty in the threaded and coupled joints than in welded casing connections.

ECONOMY

This is a subject which is difficult to analyze equitably. Viewed from the present price set-up with a total disregard for the true cost involved, we might arrive at one conclusion; but, if we attempt to base the analysis on fundamental costs, we might arrive at a considerably different answer. In the first place, it might be well to divide the discussion into a consideration of "big diameter" and "small diameter" casing.

Large diameter pipe is heavy. The cost per foot is high. The cost per complete joint of casing is high regardless of how it is put together. On the other hand, the length of the strings is relatively short, and the cost of transporting welding equipment and men to the rig and back, waiting time, etc., have to be distributed over a relatively small number of joints. Large diameter pipe need not have extra high joint efficiencies; therefore, the easiest, most rapid and economical methods of welding may be employed without undue hazard.

If we were to add up the man-hours and pro rate machine hours, taking into account the interest and depreciation on the equipment involved, from the time the raw, unthreaded pipe arrives on the finishing floor of the pipe mill, to the time when the string of casing is landed on bottom in the oil well, we would find that in large diameter casing, $10^3/_4$ inches and larger, the welded joint does, in point of fact, take less man-hours, less machine expense, and so on, per ton of pipe, than threaded and coupled casing.

On the other hand, consider the fact that on smaller diameter pipe, one threading machine that costs no more than one good welding outfit and its operator, and one tapping machine and its operator, can turn out several threaded joints in the same length of time that two men can weld one joint. Consider also, that if slip joint or sleeve joint casing is used for the welded job, that these coupling units are about as expensive—particularly if machined to proper tolerances—as the threaded couplings. In the case of butt-welded joints it will probably be necessary to provide carefully sized and rounded pipe ends at an additional cost. Consider further, that as far as the oil operator is concerned, he will have the same number of men working, in either case, and probably for more hours in the case of a welded casing job. Then it can be seen that welded casing in small sizes may not be as economical as threaded and coupled casing.

SPEED OF ASSEMBLY

Under this heading we are again forced to differentiate between small diameter and large diameter casing.

In the large sizes of pipe the operation of stabbing threaded and coupled pipe is a difficult one. The job of making up such a pipe is slow and tedious. It takes a lot of tonging after the joint is made hand-tight. In larger sizes there is greater possibility of crossing and galling of the threads, and consequent delay.

On the other hand, stabbing and aligning large welded joints presents no more problem, if as much, than smaller pipe.

It is possible to have more welders working at one time without getting in each other's way. The welders do not have to make any more lineal inches of seam, per man, than they do in the smaller sizes, and we have found that pipe larger than $10^3/_4$ inches can be run by either process in just about the same length of time. We are considering here, only the slip-joint or sleeve-joint type of welded casing because straight butt-welding is slower. We are also considering only the conventional tapered 60° V type thread because the so-called "special threads" are more rapidly run. When it comes to smaller sizes of casing, the advantage, so far, is all in favor of threaded and coupled casing. For example, in 7 inches it is possible, with regular A.P.I. threaded and coupled Grade "C" pipe, to run a 40-foot joint every three minutes; whereas, the best speed for welded casing is probably twice that length of time.

Where special joints are used, it is possible with

threaded and coupled pipe, to run a joint of 7 inches every minute. Such speeds as this appear to be completely out of the range of possibility with welding.

In the matter of speed, when time is an important factor, we are led to the conclusion that there is little choice in the case of large diameter pipe, but, that threaded connections have a distinct advantage in the smaller sizes.

EASE OF REPAIR AND SUSCEPTIBILITY TO DAMAGE

There is no question but that welded casing is far superior to any other type of joint in this respect.

In the first place, if the ends of casing intended for welding purposes are dented, a skillful man with a hammer can usually pound them back very accurately into place. The same amount of damage on a threaded joint would probably require that the pipe be laid down. In fact, only the smallest damage to threads, should ever be repaired in the field.

Modern thread protectors, now obtainable, eliminate, to a large extent, the possibility of thread damage; nevertheless, damage does occasionally occur. There is little excuse, however, for this damaged pipe to be on the racks at the time the casing is run. The most annoying damage usually occurs just as the pipe is being stabbed; that is, after the thread protector has been removed. It can be concluded, therefore, that welded pipe is easier to repair and less susceptible to damage.

FIRE HAZARD

Here we have a point that is obviously all in favor of threaded and coupled pipe. Of course, in the larger sizes the hazard of fire may be absolutely negligible, inasmuch as no gases may ever appear at depths to which such strings are set. In some infrequent cases this may not be so, in fact, there have been instances of gases becoming bothersome while setting $13^3/_8$ inches slip joint casing, at Ventura, to a depth of 5000 feet. When considering smaller strings, however, if a producing oil well is expected, there is great probability of inflammable gases around the well.

Great care in shielding off the welders will undoubtedly eliminate part of this hazard. The use of blowers, gas detectors and other safety devices, will also help; but after all, the use of such high temperatures, at such a place, presents a definitely hazardous condition.

One point, in passing, should not be overlooked: that due to the longer time required in setting the casing, more gas can find its way up the hole when welded joints are employed.

RECLAMATION

Under this heading we consider first, such cases, where due to accidental interference with the downward progress of the pipe in the hole, it becomes necessary to remove the casing and get it back in place as expeditiously as possible. In welded casing it is generally agreed that the most approved practice would necessitate remachining the pipe ends, before rerunning. It is also true that this operation is much slower and more expensive than taking the threaded connections apart.

In removing casing from a dry hole, or reclaiming it from an old well, the odds appear to be still in favor of threaded connections, except that the time element may not be so important.

WORKMANSHIP AND FINISH

Under this heading we wish to consider alignment, freedom from internal obstructions, effect of variations in wall thickness, ovality, etc.

It is probably easier to maintain a maximum error in alignment of $^3/_4$ inch in 20 feet with threaded and coupled pipe than with welded casing joints, with the exception of the sleeve type. It would also appear that this permissible error in misalignment will cause less stress concentration in threaded and coupled pipe due to the fact that threaded coupling is less rigid than welded connection.

It is generally agreed that A.P.I. tolerances with respect to wall thickness ($12^1/_2\%$ $\pm$), and out-of-roundness (1%), which have proved fairly satisfactory for threaded coupled casings, are inadequate for welded casing, particularly the butt-welded type. It is also well to call attention to the fact that in the butt-welded joint there is possibility of small obstructions, such as "tears" or "icicles" forming inside of the casing. Such obstructions may prove detrimental to casing protectors.

In the matter of outside clearances, there seems to be very little choice between the welded and threaded casing.

CONCLUSION

The most satisfactory casing joint, from an operaton standpoint, should have the maximum joint efficiency. It should be tight under the operating conditions; it should permit maximum setting depth; it should be reliable, economical, safe and free from inside obstructions; it should permit fast make-up and fast removal. Circumferential welding has proved practical, and possesses definite advantages in $10^3/_4$ inches and larger sizes. In smaller sizes, welded joints may prove more expensive. However, if tight joints cannot be obtained with threaded and coupled connection, welded joints would prove profitable even at higher cost. At the present time the welder is faced with the primary problem of speeding up his operations; reducing the setting time to at least comparable basis with threaded and coupled casing. A practical and economical means for welding casing material having in excess of 0.35% carbon would also help the cause along. Qualification of welding crews and elimination of fire hazard are also important.

WELDING HANDBOOK

The Welding Handbook of the AMERICAN WELDING SOCIETY will be available about July 20th. The book will contain some 1200 pages of the most up-to-date technical information available on welding. It was written by 90 experts and reviewed by nearly 300 other specialists, thus representing the work of nearly 400 people. Two years were consumed in the preparation of this monumental treatise on welding. Owing to the enormous expense of preparation, a limited edition has been prepared and will be offered for a short time at $6.00 a copy. Copies may be reserved by sending checks to the AMERICAN WELDING SOCIETY, 33 West 39th Street, New York, N. Y.

CARBON ARC WELDING OF COPPER Base Alloys*

By JOHN T. VREELAND†

THE carbon arc method of welding has proved in the past few years to be the most practical and economical method for the welding of copper and some of its alloys. In this discussion a description will be given of this method of welding as applied to copper, silicon bronze, nickel aluminum bronze, beryllium bronze and brasses.

Subsequent to the introduction of silicon bronze as a commercial weldable alloy possessing the corrosion resistance properties of copper, less attention has been given to the welding of copper. Recent developments in arc welding of copper are restoring this metal on somewhat of a competitive basis.

Of the two kinds of copper, deoxidized copper lends itself more readily to welding as will be explained later; but tough pitch copper (electrolytic) also can be carbon arc welded with a great deal of success, depending upon the gage and the capacity of the welding machine available. The secret in the welding of this material is to be found solely in the proper speed to use. Linear speeds of not less than 10 inches per minute, preferably 12 inches per minute, should be maintained to obtain the necessary strengths attributed to good welding Slower welding speeds have been mentioned as liable to cause the segregation of cuprous oxides in the grain boundaries of the base metal adjacent to the weld. It has been established that when tough pitch copper is heated up to approximately 1680° F. and higher, accumulations of its cuprous oxide will occur in the grain boundaries. The extent of this segregation depends upon both the time the copper is held at this elevated temperature and upon the temperature above that temperature at which the oxide begins to segregate. Considerable segregation will occur when the copper is actually melted. Experience in our laboratory indicates that no oxide segregation occurs with carbon arc welding. Because of the high reducing atmosphere, cuprous oxide adjacent to the weld is reduced to copper causing embrittlement. The degree of embrittlement will, of course, depend upon the linear speed of welding, since slow welding speeds have a tendency to reduce a greater amount of the cuprous oxide. Bend values on carbon arc welds are not particularly good because of this condition.

To minimize porosity in the weld-metal due to the high heats required, an oversized filler rod should be used. The type of filler rod that has proved most successful is phosphor bronze containing approximately 1/4% residual phosphorus. Any of the commercial phosphor bronze mixtures with tin contents from 1 1/2 to 10% may be used. For gages over 3/16 inch thick, the higher tin mixtures take preference, because of their high degree of fluidity, which materially aids in maintaining high welding speeds. For gages under 3/16 inch, the 1 1/2% tin mixture should take preference, because of its lower cost; since results obtained in the welding are equivalent to those obtained using the higher tin alloys.

Carbon arc welding of copper is limited to 1/4 inch thickness; for above that gage the tremendous heats that are required to accomplish the welding in a single bead, makes the method quite impractical. Because of the hot shortness of the weld-metal, it is difficult to perform multiple-bead welding. Figure 1 is a carbon arc weld of 1/8-inch tough pitch copper using 1 1/2% tin filler rod.

It is possible to patch up leakers, obtained in pressure vessels, by using a small size rod with a minimum amount of heat. It is not advisable to continue applying the arc intermittently at a spot which is difficult to patch. The heat that is gradually built up will cause the weld-metal to crack due to the stresses set up at that point.

Deoxidized copper can be welded much more easily than electrolytic copper since welding speeds are not a governing factor. In deoxidized copper in which no cuprous oxide occurs there can be no reduction of oxide adjacent to the weld. The same precautions as for electrolytic copper must be taken to prevent difficulties, which are shortcomings of the welding rod used.

Table 1—Carbon Arc Welding Electrolytic Copper

Using Low Tin Phosphor Bronze

Gage Base Metal	Filler Rod Diam.	Closed Circuit Amperes	Closed Circuit Voltage	Tensile Strength Weld	Remarks
1/16 in.	1/8 in.	130–190	25–40	30,000	
1/8 in.	3/16 in.	180–240	30–45	28,700	
3/16 in.	/16 in.	270–330	40–55	28,800	Beveled to 90° inc. l.
1/4 in.	3/8 in.	320–360	40–55	27,500*	Beveled to 90° inc. l.

* The use of high tin Phosphor Bronze would improve tensile strength to 29,000–30,000 lb./sq. in.

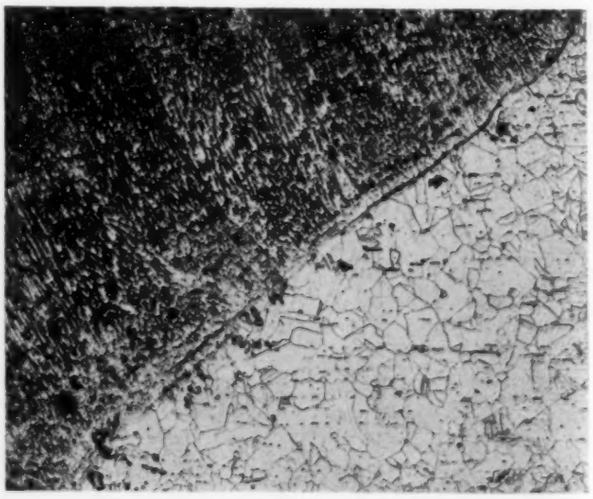


Fig. 1

Mag. 75 × Etchant—Chromic Acid

1/8-Inch Copper Tough Pitch Sheet Welded with 5/16 Inch Low Tin Phosphor Bronze Rod

* Presented at April 19th Meeting, New York Section, AMERICAN WELDING SOCIETY.

† Metallurgical Engineer, Chase Brass & Copper Co., Inc., Waterbury, Conn.

Fig. 2

Mag. 5 × Etchant—Chromic Acid + HNO_3

1/2-Inch Silicon Bronze-Welded Using High Heats. Weld-Metal Not Subjected to Cold Working

Note large columnar crystals which are typical of chill cast metal. Structure indicative of low strengths

Silicon bronze, a commercial alloy containing approximately 3% silicon and approximately 1% or less of zinc, manganese, tin or iron, has developed into a major industrial alloy because of its high strength and ease of welding. Because of its exceptional resistance to corrosion, the alloy is widely accepted as a material to be used for the fabrication of industrial units of all types to withstand severe service conditions. The success of silicon bronze in its many applications is directly responsible to its weldability and to the development of the carbon arc method.

The heat conductivity of silicon bronze being approximately 1/15th of that of copper, high heats are not required to obtain good results. With the use of high heats and slow welding speeds, tensile values obtained in the weld will be lowered. The increased heat affects the base material as well as the weld-metal structure. Note Fig. 2, in which large columnar crystals may be seen, which is typical of cast metal. Any method used to minimize the heat effect will yield better weld results, provided the quality of the weld-metal is retained. Note Fig. 3, in which equiaxed crystals, typical of wrought metal, are clearly seen below the top weld beads.

The use of back-up bars of copper has a tendency to decrease the tensile strength of the weld because of the increased heat effect on the base metal. Higher heats must be used to compensate for the heat taken up by the back-up. In the case of welders not sufficiently acquainted with the carbon arc technique, slow welding with these higher heats lowers the resulting weld strength as much as 5000 lb./sq. in. On the other hand, the use of back-up bars makes the welding much easier since it eliminates the danger of burning through. It is advisable to use such back-up bars with inexperienced welders to insure sound welds until the welder acquires the necessary experience.

For the welding of gages of 1/8 inch to 3/16 inch inclusive it is advisable to use back-up bars to insure good penetration and elimination of any welding on the under side. An experienced welder can very easily obtain good uniform penetration without the use of back-up bars on 1/8-inch gage, but as the gage increases, the ease of obtaining good uniform penetration decreases. For this reason, it is advisable to use a back-up bar for gages between 5/32 inch and 3/16 inch, unless welding on the under side is planned. Gages 1/4 inch to 5/8 inch which are beveled can be easily welded without a back-up and good uniform penetration obtained.

Typical results obtained on different gages of silicon-bronze, with or without back-up bars, are shown in Table 2. Note the effect of back-up bars on the resulting tensile strength.

Considerable interest has arisen recently in A. S. M. E. Unfired Pressure Vessel Code work. This code calls for tensile values in the weld equal to 100% of the minimum tensile strength specified (52,000 psi) for the base metal. Since the weld-metal is essentially cast material, it is quite impossible to obtain 52,000 psi in an unreinforced weld without some treatment of the weld-metal. Figures 2 and 3 show the types of weld structures obtained in the normal carbon arc weld. Tensile strengths of these welds (unreinforced) were approximately 47,000 psi and 49,000 psi. Figure 4 shows the change in the structure of the weld-metal due to the cold working by peening and to annealing due to subsequent welding. This type of structure is typical of that obtained in gas welding. Figure 5 shows the different zones obtained in a properly joined and peened weld, to give tensile strength values (unreinforced) of 52,000–60,000 psi.

To insure minimum tensile values of 52,000 psi in the weld, it is essential that the base metal have a tensile

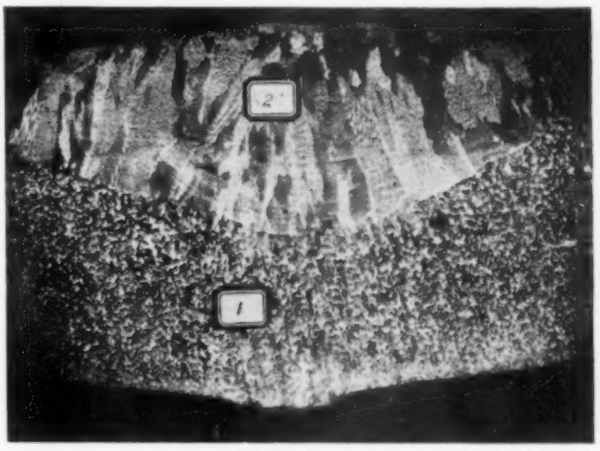


Fig. 3a

Mag. 5 × Etchant—Chromic Acid + HNO_3

1/2-Inch Silicon Bronze-Welded Using Low Heats. Weld-Metal Not Subjected to Cold Working

Note (Area 1) equiaxed crystals typical of annealed wrought metal and gas-welded structure. Note (Area 2) smaller columnar crystals than shown in Fig. 2

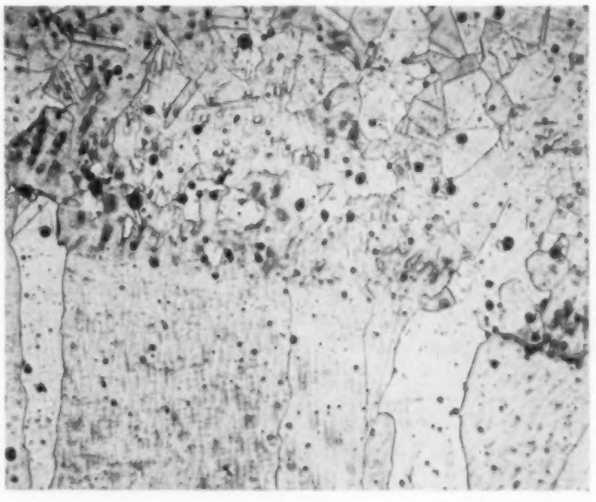


Fig. 3b

Mag. 75 × Etchant—Chromic Acid + HNO_3

Same as Above. Picture Taken at Junction of Equiaxed Crystals and Columnar Crystals

Note the tendency toward uniform equiaxed crystals

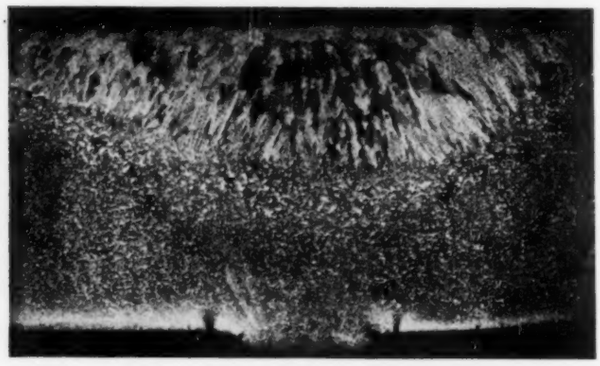


Fig. 4a

Mag. 5 × Etchant—Chromic Acid + HNO_3

½-Inch Silicon Bronze-Welded with Low Heats. Weld-Metal Subjected to Cold Working

Note fine equiaxed crystals and small columnar crystals. This structure is indicative of high strengths

Fig. 4b

Mag. 75 × Etchant—Chromic Acid + HNO_3

Same as Above. Picture Taken at Junction of Equiaxed Crystals and Columnar Crystals

Note the uniform grain size of equiaxed crystals (typical of annealed wrought metal)

strength of 55,000 psi minimum. For best results, base metal $^1/_4$ inch to $^3/_8$ inch thick should be 55,000 to 60,000 psi. If the base metal is $^3/_8$ inch to $^5/_8$ inch thick, the tensile strength should be 60,000 to 65,000 psi. The effect that the tensile strength of the base metal has on the resulting tensile strength of the weld is indicated in Table 2.

Elongation of 40% minimum, which is specified for A. S. M. E. Code welding, obtained by a free-bend test, can be easily met by any quality of welds subjected to peening. Relief annealing of peened welds improves the free-bend value by approximately 10%. Weld-metal unpeened will meet the required minimum, provided the welding heats and speed of welding are controlled to prevent the forming of excessively large crystals in the weld.

The recommended welding procedure for successful carbon arc welding of all silicon bronzes is given in Table 3. For metal $^5/_8$ inch and $^3/_4$ inch thick, it is advisable to use parallel beads at the top of the welding groove in order to increase the lineal welding speed and to reduce the effect in the base metal. By this procedure and subjecting the weld-metal to cold working by peening, tensile strengths over 52,000 psi may be obtained when

Table 2—Welding Results for Silicon Bronze

Gage Base Metal	Welding Groove	Tensile Strength Base Metal Lb./Sq. In.	Tensile Strength Weld Lb./Sq. In.	Remarks
$^1/_4$ in.	75°	51,200	46,700	Back-up plate used. No peening last bead.
$^1/_4$ in.	75°	67,650	50,400	Back-up plate used. No peening last bead.
$^1/_4$ in.	75°	67,650	56,300	Back-up plate used. Peened.
$^1/_4$ in.	75°	67,650	51,500	No back-up plated used. No peening.
$^1/_4$ in.	75°	67,650	61,300	No back-up plated used. Peened.
$^1/_4$ in.	75°	67,650	53,500	No back-up plated used. No peening last bead.
$^1/_4$ in.	75°	67,650	60,000	Back-up plate used. Peened.
$^1/_2$ in.	90°	53,800	50,000	Back-up plate used. Peened.
$^1/_2$ in.	90°	56,000	52,600	Back-up plate used. Peened.
$^1/_2$ in.	75°	60,000	55,800	Back-up plate used. Peened.
$^1/_2$ in.	75°	60,000	57,000	No back-up plate used. Peened.
$^1/_2$ in.	75°	60,000	48,200	No back-up plate used. No peening.
$^1/_2$ in.	75°	60,000	50,000	No back-up plate used. No peening last bead.
$^5/_8$ in.	90°	56,200	51,800	Back-up plated used. Peened. —Back-up plate used. Peened.
$^5/_8$ in.	90°	56,200	52,650	Two parallel beads used on top —Back-up plate used. No peening last layer.
$^5/_8$ in.	90°	56,200	50,700	—Two parallel beads used on top

the welding is done from one side only, using a single V welding groove.

As already pointed out, tensile strength values from 45,000 psi to 52,000 psi can be obtained without any treatment of the weld-metal, whereas tensile values from 52,000 psi to 61,000 psi can be obtained if the weld-metal is cold worked by peening. All layers of weld-metal except the first one are peened thoroughly with

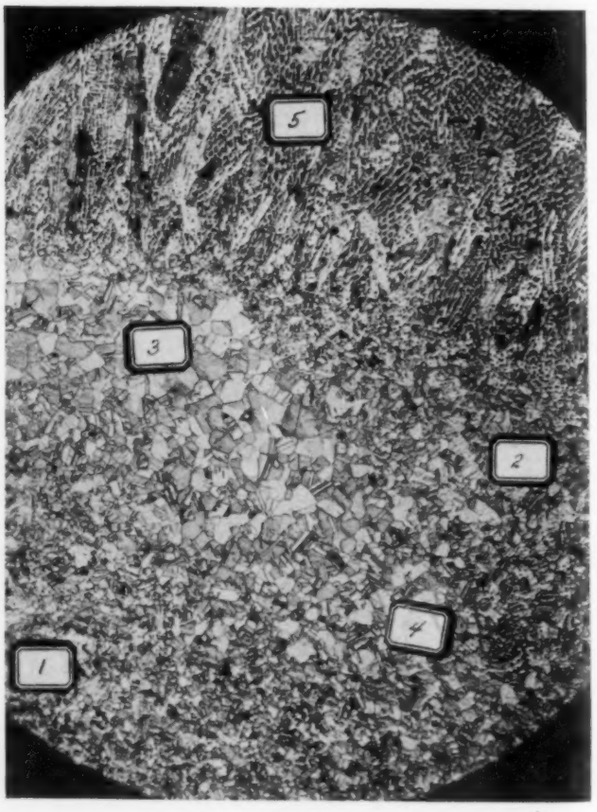


Fig. 5

Mag. 50 × Etchant—Chromic Acid

Area 1—Base Metal
Area 2—Recrystallized Weld-Metal
Area 3 & 4—Effected Base Metal Zone Due to Welding
Area 5—Weld-Metal—Top Bead

Note the above areas at the weld junction just below the top bead. All of these areas have an important bearing on the resultant strength and ductility of weld

Table 3—Recommended Welding Procedure for Silicon Bronze

Plate Thickness	Welding Groove	No. Beads	Filler Rod Diam.	Carbon Electrode Diam.	Closed Circuit Amperage	Closed Circuit Voltage	Weld Tensile Strength psi	Remarks	
1/8 in.	..	1	5/32 in.	1/4 in.	80–140	20–35	52,000–55,000	Not peened.	Base metal 55–60,000
5/32 in.	..	1	3/16 in.	1/4 in.	110–170	20–35	52,000–55,000	Not peened.	Base metal 55–60,000
3/16 in.	..	1	1/4 in.	5/16 in.	160–220	25–40	50,000–53,000	Not peened.	Base metal 55–60,000
1/4 in.	75°	3	1/8 in. 5/32 in. 1/4 in.	1/4 in. 1/4 in. 5/16 in.	80–140 110–170 140–200	20–35 20–35 25–40	54,000–58,000	Peened T.S. Base metal 55,000–60,000 lb./sq. in.	
5/16 in.	75°	3	1/8 in. 5/32 in. 5/16 in.	1/4 in. 1/4 in. 3/8 in.	80–140 110–170 140–200	20–35 20–35 25–40	54,000–58,000	Peened T.S. Base metal 55,000–60,000 lb./sq. in.	
3/8 in.	75°	4	1/8 in. 5/32 in. 3/16 in. 5/16 in.	1/4 in. 1/4 in. 1/4 in. 3/8 in.	80–140 110–170 120–180 140–200	20–35 20–35 25–40 25–40	52,000–56,000	Peened T.S. Base metal 55,000–60,000 lb./sq. in.	
7/16 in.	75°	4	1/8 in. 3/16 in. 1/4 in. 5/16 in.	1/4 in. 1/4 in. 5/16 in. 3/8 in.	80–140 110–170 130–190 160–220	20–35 20–35 25–40 25–40	53,000–57,000	Peened T.S. Base metal 60,000–65,000 lb./sq. in.	
1/2 in.	75°	5	1/8 in. 3/16 in. 1/4 in. 5/16 in. 5/16 in.	1/4 in. 1/4 in. 5/16 in. 3/8 in. 3/8 in.	80–140 110–170 130–190 160–220 160–220	20–35 20–35 25–40 25–40 25–40	53,000–57,000	Peened T.S. Base metal 60,000–65,000 lb./sq. in.	
5/8 in.	90°	6	5/32 in. 1/4 in. 3/8 in. 3/8 in. 3/8 in. 3/8 in.	1/4 in. 5/16 in. 3/8 in. 3/8 in. 3/8 in. 3/8 in.	80–140 120–180 180–240 180–240 160–220 180–240	20–35 20–35 25–40 25–40 25–40 25–40	52,000–55,000	Peened T.S. Base metal 60,000–65,000 lb./sq. in.	

a round nosed tool designed to fit the welding groove, so as to permit maximum working of the weld-metal. No peening is done on the first bead because of the danger of cracking, since the amount of weld-metal present is not sufficient to withstand the strain of hammering. It is advisable to avoid overworking the weld-metal, particularly at either end of weld, because of the danger of cracking. In working on vessels large enough to permit entrance, it is advisable to use a manual method of back-up while peening. If the vessel is too small to permit entrance, it is advisable to use a back-up bar to permit good peening. In some cases, the back-up can be made of 1/8-inch to 3/16-inch gage silicon bronze and left as a reinforcement for the welded joint.

As has been stated, the welding of silicon bronze has yielded excellent results, but precautions must be followed to minimize certain difficulties. Removal of dirt, grease and oxides (black and red) must be done by pickling or grinding to insure satisfactory results. Slag from each welding bead must be removed to obtain maximum density in joints requiring multiple bead welding. Proper flux should be used, consisting of 90% powdered fused borax and 10% powdered sodium fluoride. The flux is best applied to the cold work, sparingly, in the form of a light paste with alcohol applied with a brush.

On hot work, the dry, powdered flux may be sprinkled on. Excessive amounts of flux are to be avoided, in order to insure welds free from slag or flux inclusions. Better results can be obtained with no flux than can be expected if excessive flux be used. Proper welding speeds, from 5 inch/min. to 14 inch/min., depending on size of filler rod used, should be maintained to minimize heat build-up, which is the cause of hot short cracks, due to expansion and contraction of the base metal.

Tacking every six to eight inches with substantial tack welds should be done, to minimize the movement of the base metal, due to welding heat. In multiple bead welding, it is essential that the welding of all beads after the first one be started approximately two inches in from the edge. After completing that portion of the weld, the weld bead can be finished by welding from start of the bead back to the edge. The purpose of this is to minimize any danger of cracking, by having cold weld-metal back of the arc to withstand the weld stresses set up while welding. This can also be accomplished by starting at the edge and stopping for a second after approximately two inches of weld bead has been laid down. After a stop has occurred in a weld bead, it is advisable to strike the arc at a point approximately one inch back from the start. No filler rod is added until the arc is brought up to the point where the stop occurred. This is done to insure overcoming any crater cracks at the stopping point and to insure good fusion of the new weld-metal at that point. The lineal travel of the arc from the starting point to where filler rod is to be added should not exceed the rate at which the filler rod is to be added.

When welding nozzles, it is good practice to have the nozzle fill the hole as closely as possible. If any great space is present, weld-metal deposited in that area will have a tendency to sag through, with a liability to cause leakers, due to minute cracks in that area. It is advisable to build up the opening to reduce the space between the nozzle and the edge of the opening. This procedure will yield excellent results and save trouble and time in attempting to patch up leakers.

Figures 6 and 7 are X-ray pictures of welds. Note that Fig. 6 is a quality weld. Figure 7 shows a defective area adjacent to a spot where burning through occurred. This is typical of areas adjacent to places where burning through occurs.

Fig. 6—X-Ray Picture Showing Quality Weld on 3/8-Inch Silicon Bronze Plates

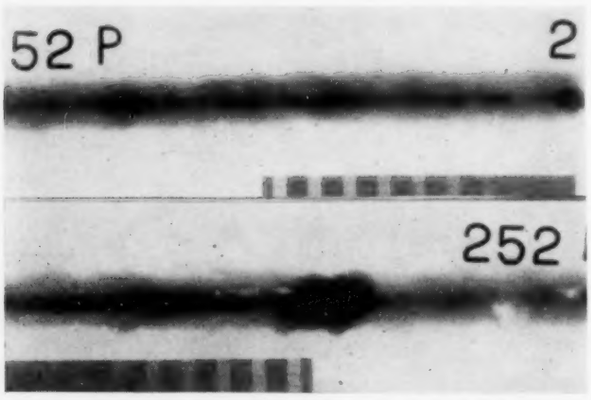


Fig. 7—X-Ray Picture Showing Defects at Area Where Burning Through Occurred. This Is Typical of Such Areas and Should Be Looked for in Pressure Vessels

Quite often in fabricating shops, it is necessary to join copper and bronze to steel and to each other. Any one of these unions can be accomplished with the carbon arc method and the use of the proper rod. The success of welds on the steel side is found in avoiding any melting of the steel. To accomplish this, an oversize bronze rod is used. The arc is carried on the rod on the bronze side, thus obtaining a brazed joint on the steel side. When joining silicon bronze to steel, it is advisable to flux both steel and bronze. All dirt, grease and oxide should be removed from both steel and bronze to insure good results. A silicon bronze rod is recommended for silicon bronze-to-steel welds. For copper-to-steel welds, low tin bronze rod should be used. Cleanliness of both metals is important but no flux is required. Because of the necessity of higher heats as compared to silicon bronze-to-steel welding, particular care must be taken to avoid melting the steel. Low tin bronze rod also yields best results for welding copper to silicon bronze. This is true only when the bronze is fluxed and heats as required for copper welding used.

Carbon arc brazing with silicon bronze rod also finds an application in joining galvanized iron. By the use of this method, a minimum amount of zinc is disturbed, and with very little discoloration. The strength of the joint is surprisingly high, approaching that of an all steel weld.

Welding of such alloys as yellow brasses, red brasses, leaded bronzes, aluminum bronze or nickel-aluminum bronze and beryllium bronze can also be accomplished with certain degrees of success by means of the carbon arc method. Using silicon bronze rod, both yellow brasses and red brasses are welded with fair results. Because of the high heat of the arc, a considerable amount of zinc is volatilized from the base metal causing some porosity in the weld-metal. The strengths, however, are sufficiently high to permit the method where some structural strength is required. In the welding of aluminum bronze or nickel aluminum bronze, good results from a standpoint of density and strength are obtained with silicon bronze. It is not advisable to use a rod containing aluminum since the aluminum oxide cannot be fluxed off satisfactorily, particularly when multiple bead welding must be done. The aluminum oxide being quite refractory forms a light tough web which becomes folded in the flowing weld-metal and does not rise to come in contact with the molten flux on the surface of the weld-metal. The welding of beryllium bronze requires a considerable amount of investigation to obtain a method to free the weld-metal of beryllium oxide which is much more refractory than aluminum oxide. Fairly good results can be obtained on thin gage metal using silicon bronze flux. Leaded bronzes can be welded with a minimum amount of trouble with silicon bronze rod. Care must be taken in order to minimize the heat dissipation into the base metal. Since leaded alloys are hot, short, high welding stresses or movement of the metal may cause cracking. By eliminating lead from the filler rod, a dense weld is pretty certain. A weld made with silicon bronze rod by this method will contain a small percentage of lead after the welding operation.

This concludes the discussion on carbon arc welding but it may be of interest to say a few words about metal arc welding. This method of welding of copper and its alloys does not have the wide application or ease of operation as found with carbon arc welding. The reason for this is directly due to the unstable arc obtained and the uncertainty of the results. Coatings are used for the sole purpose of stabilizing the arc. Silicon bronze coated electrodes are being used with good results. Tensile strengths obtained in such joints are lower than obtained with carbon arc welding. For respectable values, cold working of the weld-metal is necessary. Structures obtained in metallic arc welds of silicon bronze contain many more dendrites, a condition which is characteristic of high temperature molten metal that is chilled rapidly.

Welding of tough pitch copper can be best accomplished by the metallic arc method. By this method, actual welding is accomplished with multiple bead welding, being possible without obtaining cracks in the weld-metal. The success of such a rod will be found in the coating required to give good fluidity and arc stability. The core should be a mixture having a melting point slightly below that of copper and as a bare electrode should have a fairly stable arc.

Tensile values obtained on thicknesses up to 3/16 inch will run approximately 30,000 lb./sq. in. It is questionable at this time to predict results on 1/2 inch thick copper since density of the weld-metal may be slightly inferior. With this method of welding, no reduction of cuprous oxide is obtained nor is it necessary to weld with a back-up bar. These two points alone are sufficient to warrant the complete development of this method, which at the present time is being undertaken.

ACKNOWLEDGMENTS

I wish to extend my appreciation for the valuable assistance in compiling these data to Dr. D. K. Crampton, Research Director, Chase Brass & Copper Co. Inc.

WELDING HANDBOOK

Quiet a few companies are purchasing the AMERICAN WELDING SOCIETY WELDING HANDBOOK in quantity lots for all their engineers, supervisors and foremen. This 1200-page Handbook represents two years' work on the part of four hundred experts. Quantity lot price $5.00. Orders will be filled as long as the supply lasts.

STAINLESS ALLOY WELDED

Plate and Castings in Corrosion-Resisting Pressure Equipment*

By RANDOLPH SIMPSON†

IN PRESENTING a paper of this nature one should perhaps go back for a few years to acquaint his listeners with some of the reasons for the development of a branch of welding which is rapidly becoming a very exact science.

For many years preceding the Great War metallurgists of at least three great countries, namely, Germany, England and our own United States, were working with might and main to present to the world a steel or steels which would aid in counteracting one of the world's greatest evils—the corrosion of steels. It has been estimated that this evil was costing the world upward of a billion dollars a year. At the outbreak of the War, scientists of the three countries mentioned, through separate endeavor, had reached nearly the same conclusion; that is, that steel with high-chromium content, twelve per cent and better, would under certain conditions resist the corrosive action of the atmosphere, fruit acids and nitric acid. In England and the United States, at least, this new steel was called stainless. Experiments along the same lines were continued during the war, and shortly after peace came a new steel was brought out which contained not only high percentages of chromium, but also large quantities of nickel. This latter steel was non-magnetic, while the straight chromium steel was magnetic.

Metallurgically speaking we call the steels austenitic and ferritic stainless steels. It was not until shortly before the depression that the use of the austenitic stainless steels assumed any great proportions in the United States, but since that time each succeeding year has seen larger and larger amounts being made and sold, not only in rolled, but in cast forms. Perhaps it should be mentioned at this time that among the first austenitic stainless steels in use in the United States was the so-called 18–8 steel; and, while there have been a number of variations of this combination of chromium and nickel to suit the different conditions which have arisen, the 18–8 seems to be the most popular generally, but because of more corrosive conditions existing in some industries it was found that other combinations of these two elements, with the addition of some special element, had to be used to obtain maximum corrosion resistance.

Industry, finally awakened to the fact that a steel was at last available, the use of which would materially aid, if not entirely whip, some of its most vexatious corrosion problems, began calling for this steel in all kinds of difficult cast and fabricated-plate forms; hence our welded structures and the call for a paper of this nature before this Western Metal Congress.

It may be stated quite emphatically, especially for the benefit of those who know little about this steel, that it lends itself very readily to welding. For very thin gage plate, acetylene welding is quite extensively used. In this kind of welding the flame should be held as close to neutral as possible, slightly on the reducing side. Every caution should be exercised to protect the molten metal from oxidation and the absorption of carbon into the weld. The underside of the weld is usually protected with a flux, and great care is taken to prevent warpage and buckling by the proper use of clamps. Puddling should not be resorted to, and welding should be done as rapidly as possible. Filler rods should be of such analyses as to deposit metal of approximately the same analysis as the material being welded.

Electrical resistance welding, under which general heading comes spot and seam, together with flash welding, is used to some extent with the stainless steels. Shops equipped for spot welding mild steels may use the same equipment for stainless steels using less time and heat.

Some years ago it was discovered that if hydrogen was heated to a sufficiently high temperature it was broken down to its atomic state; high local temperatures could be obtained when these atoms combined again upon cooling. This discovery lead to the method known today as atomic-hydrogen welding. To weld by this method a stream of hyrdogen is directed through an arc maintained between two small tungsten electrodes; the molecular hydrogen is dissociated into atomic hydrogen with a consequent large absorption of heat. The stream of gas is directed at the spot to be welded. By the time the stream of gas reaches the metal to be welded it has again reverted to the molecular state, giving up the absorbed heat to the metal with which it comes in contact. The metal fuses and welds together, aided by the burning of the hydrogen which, of course, generates more heat. In this process there is an entire lack of either oxidation or carburization with a consequent smooth, even weld when properly done.

Since perhaps the bulk of all stainless-steel welding is done by the electric-arc method, and since the company I have the honor to represent deals with that method almost exclusively in their cast and fabricated stainless steel products, this paper will be devoted to that phase of welding. While my company casts and fabricates many different types of both ferritic and austenitic stainless steels, the paper will be confined to the latter steel, since most of our work falls into that category. The steels discussed will be the 18–8, 18–8S, 18–8–3Mo and 18–8S–3 Mo. For the benefit of those who are not perhaps familiar with these symbols, let me explain that 18–8 means eighteen per cent chromium and eight per cent nickel. The suffix (S) indicates maximum 0.07 carbon, and the 3Mo means three per cent molybdenum.

Since practically all of the physical problems met with in the welding process by any method arise directly or indirectly from the application of the heat necessary to produce the weld, a very brief examination of the thermal properties of the stainless alloys will greatly help in con-

* Paper presented at Western Regional Conference of the AMERICAN WELDING SOCIETY, Los Angeles, Calif., March 21–25, 1938.

† Electric Steel Foundry Co., Portland, Oregon.

sidering the practice and technique to be used. For sake of contrast we may compare these properties with those of a low-carbon mild steel which is familiarly and successfully fabricated almost universally and whose behavior is pretty generally understood; if we let the value of the mild steel be represented in each case by the number 100, we have the following relative values for the 18–8 type:

Specific electrical resistance	640
Specific heat	110
Melting point (see note)	95
Thermal conductivity	33
Coefficient of thermal expansion	145

(NOTE: Not an absolute ratio $\frac{2570 \times 100}{2700} = 95$)

The first, electrical resistance, plays an important part, of course, in all electric welding, while the last two prove troublesome in producing a localized highly treated area adjacent to the weld and serious warping or distortion during fabrication and cooling.

The research departments of all the large steel companies are more nearly in agreement when the topic of electric welding of austenitic stainless steels is brought up than on almost any other phase of steel subjects; they closely agree to the following points, viz: tough, ductile, highly satisfactory welds can be and are produced if the proper welding electrodes of approximately the same analysis as the material to be welded are used. In work up to $^1/_4$-inch plate the welding electrode should be connected to the positive terminal of the generator, and the plate to the negative—a set-up known to welders as reversed polarity. Coated rods should be used and the coating should be free from carbonaceous matter; the welding rod should not contain more than 0.07 per cent carbon; the coating on the rods or electrodes should be made of a composition of elements which will insure a free flowing of the melted metal by maintaining a steady arc with a minimum of splatter. The welding should be done toward the flow of the current which should be regulated at the welding machine. The following regulation table is frequently recommended, but is by no means absolute or fool-proof:

$^3/_{32}$-inch electrode 35–40 volts open circuit with 50–75 amperes
$^1/_8$-inch electrode 40–45 volts open circuit with 75–100 amperes
$^5/_{32}$-inch electrode 50–60 volts open circuit with 100–125 amperes
$^3/_{16}$-inch electrode 55–65 volts open circuit with 150–175 amperes
$^1/_4$-inch electrode 70–80 volts open circuit with 225–300 amperes

In heavy work straight polarity is often used and has been known to produce very satisfactory welds.

WELDING OF CASTINGS

It goes without saying that the acme of perfection has been reached in an austenitic stainless-steel casting when no welding is needed. Many castings of simple and even complicated construction can be and are made in foundries familiar with these steels which need no welding. There are, however, many extremely complicated castings which, in spite of the care used by the designing engineer to have them as simple as possible, are still the cause of many headaches to the foundryman whose duty it is to have them made. Due to differences in metal sections, multiplicity of cores and sand cutting by the hot metal, many castings of intricate design can hardly help having blemishes or perhaps draws because it is extremely difficult to feed them fully. In such cases such a casting must be thrown away or welded. In case it is decided it can be welded satisfactorily, the casting is sand-blasted and thoroughly examined for the minutest flaws of any description, and such flaws chipped out until solid metal is found beneath the flaw. Care must be taken that no spongy metal is left in the cut and that there is no oil, grease, scale or water near the part to be welded. To weld, the electrode should be positive, with as low voltage as will hold an arc. The weld should be laid smooth, without piling up, since the heavy coating will require excessive peening to clean. Any peening done should be just enough to clean coating off the weld. Do not use excessive heat, as excellent penetration may be had with fairly low heats. All the electrode manufacturers furnish welding rods of the right analysis; in sizes from $^3/_{32}$–$^1/_4$ in., which makes it convenient to reach the bottom of a vee or a hole, whichever it may be. In case of a large hole it is recommended that the beads be run in opposite directions so that weld may be tied in better. Where more than one bead is necessary, care should be taken that each be thoroughly cleaned of all slag and dirt of any description before another is laid. A weld made in this manner will be as good and as sound as the parent metal and, when the casting is subsequently heat-treated, will stand any pressure the casting will stand and will be equal to the casting in corrosion-resisting qualities.

To avoid having defects in complicated pump castings, whose outlets may wind up with a flanged end, my company, in many cases, has found it convenient to cast such flanges separately and weld them to the outlet of the pump afterward. Such a practice many times simplifies the job and gives the customer a better casting.

WELDING OF PLATE

The welding of stainless-steel plates of the 18–8 and 18–8–3 varieties is a much simpler job than that of welding the same steels in castings. This is true because, for the most part, this type of welding is all open work. Very light plate work should always be clamped. This may be done in numerous ways, depending on the knowledge and ingenuity of the welder. When the welder finds it is necessary to tack plates to hold them in position while welding, care must be taken that the tack be an intregal part of the finished weld. Best results are obtained if tack can be made on the opposite side of the weld. As plate gets heavier, beveling becomes necessary. These bevels should be prepared wider than in ordinary steel work so as to afford a more open kerf, the better to insure proper fusion. Puddling of these stainless steels must not be resorted to since poor welds will be the inevitable result of such practice.

Voltages and amperages, as recommended by rod manufacturers, are generally correct. As the heat is low, compared to mild steel, a generator set with arc stabilizing adjustment is most suitable, so that the welder can more readily attain the ideal condition of heat and arc length to accomplish maximum penetration and minimum splatter.

Where multiple pass welds are necessary, too much care cannot be taken in cleaning the preceding beads to exclude the possibilities of gas and slag pockets in the succeeding welds. If work can be arranged in such fashion that the slag carries away more readily, the resulting weld would be denser. If a shop has hard and set rules about welding ordinary steels, then it is even more important that these rules be made still more exacting when dealing with the austenitic stainless steels. It goes without saying that since these steels are so expensive, and since fabricated work of every description is now being made with them, none but the most skillful of workers should be employed; then all work be most carefully scrutinized for the slightest defect. All this care must be

taken because this fabricated work will most likely go into plants where highly corrosive chemical conditions exist and maximum temperatures and pressures must be withstood, and even small leaks may be very dangerous to other, less resistant, equipment and possibly human life. Even though the pressures to be handled are moderate, such as ordinary boiler pressures of 200 psi and less, the material should be tested under much higher stresses and patiently inspected for these minute flaws which, in ordinary service, would probably seal themselves in course of time with deposits from the materials or liquids handled. It is well to remember that many of these blemishes or porous spots in a weld may contain oxides or residues from the flux which might start electrolysis by the corrosives to be handled, and thus become increasingly dangerous during the life of the fitting or part. This consideration is entirely separate from that of strength and is often given little attention.

In plants where austenitic stainless steels must be used, though the corrosive conditions met with are not particularly severe, the ordinary 18–8 with the carbon content of 10 has been found excellent for the job, and plates used for such type of work may be welded with a like material with no subsequent heat treatment. Under more corrosive conditions 18–8S should be used with 18–8S welding electrodes; such work may or may not require subsequent heat treatment. Under still more corrosive conditions the 18–8S–3 plate is used, and all welding is done with electrodes of the same analysis. Subsequent heat treatment, under such conditions, may or may not be necessary and if so is performed by heating the work to about 2000° F. and rapidly cooling. In work of light sections air cooling is fast enough, but heavier work should be water quenched. It should be understood that this heat-treatment is not done to refine the grain of the steel since these steels do not respond to such treatment like other steels. In these steels the grains actually grow in size; the heating and rapid cooling is done to trap the carbides in the solid austenitic solution, thus putting the steel in its best condition to resist corrosion. If this heating and rapid cooling is not resorted to, a small zone on either side of the weld is in excellent shape to invite corrosive attack since, in these two zones, there will be precipitated carbides.

The reason for their presence is as follows, viz.: when two pieces of austenitic stainless steel are welded together the metal on either side of the weld becomes heated to points high enough to cause carbides to be precipitated. The temperature at which this precipitation starts is usually considered to be about 900° F. Since these carbides cannot be re-absorbed in the solid austenitic solution until a temperature of at least 1800° F. has been reached, obviously all parts of the metal which have attained temperatures between 900° F. and 1800° F., because of the welding operation, will contain more or less of them. In cooling, the weld and surrounding metal which has reached temperatures in excess of 1800° F. will cool fast enough, even in air, to trap such carbides in the solid solution of austenite, but the rest of the metal which has been heated between 900° F. and 1800° F. will, when cold, still contain unabsorbed carbides. The width of these zones will be a function of the mass of the weld and the expertness of the welder; if he uses a lot of heat and is slow about his work, then the zones will be of greater area than if he did his work more rapidly and efficiently.

It has been claimed in the past that if the carbon content of the plate and welding rod was less than 0.07 per cent C, heat treatment was not necessary. We have found this statement to be false in that even with the carbon content that low, some precipitation does occur. To combat the precipitation, stabilized 18–8–Ti was produced; a product which contained titanium usually in amounts six times the amount of carbon contained. This material was faulty under certain conditions, since the heat of welding oxidized off some of the stabilizing element, thus leaving the weld and surrounding zones vulnerable.

In the last few years columbium in quantities ten times the amount of carbon has been introduced as a stabilizer and, in jobs where subsequent heat treatment is impossible, probably makes the best installation particularly when operating at elevated temperatures and under highly corrosive conditions. My company has not, as yet, resorted to the use of columbium in either our fabricated materials or our castings. We have found that when 18–8S–Mo is used for our fabricated parts, our standard 18–8–3 analysis for our castings and both kinds of work given our regular heat treatment they, separately or in combination, will withstand the most corrosive work with which we have to contend.

The bulk of the 18–8S–Mo which we use is installed in the sulphite pulp mills and I very much doubt if there is any combination of the elements that go to make up stainless steels which will give the general satisfaction this material does. This material finds its way into cast pipes, top and bottom neck liners, various outlets, standard and special fittings, and valves of all descriptions. Pumps used in this industry on the Pacific Coast are for the most part entirely composed of it. This industry demands a great deal of this type of plate, which is fabricated into many different shapes besides thousands of feet of various sized tubes which are used in heat exchangers. A great deal of this work, besides having to withstand highly corrosive conditions, must also withstand heavy pressures. The electric welding, when done well, stands up perfectly.

CHOICE OF WELDING RODS OR ELECTRODES

There are many brands of welding electrodes on the market and this paper would be far from complete if some few things were not said about them. Each company specializing in their production is usually able to furnish them in any desired size and to any desired guaranteed analysis. That there is a great deal of difference in these electrodes is, unquestionably, true but the difference is for the most part in the coating and not the steel. The producers are very jealous of their coatings, trying in every way to keep their various formulas secret. The function of the coating is to aid in maintaining a steady arc, prevent oxidation and to aid in purifying the deposited metal. Electrodes whose coatings have become moist should never be used, as poor welds will be the inevitable result. Some coatings will crack badly and drop off when an electrode is in the process of cooling after having been in use. Much waste occurs if this happens, since the bare electrode remaining cannot be used again in this process of welding. A great many electrodes seem to have a tendency to build-up and splatter.

The ideal electrode, then, is one which gives the smoothest bead, holds the steadiest arc, has maximum penetration with minimum splatter, results in the least waste and gives the densest and most corrosion-resisting weld.

All the large steel companies can produce good stainless steel rods, but all coating manufacturers do not produce the best coatings. It has been claimed that some coating manufacturers have introduced elements into

their mixtures for the purpose of making a smooth running electrode which may be dangerous to the health of welders, especially when the welding is being done in close quarters and places with poor air circulation.

In bringing this paper to a close, it might be mentioned that while manual electric welding of the austenitic stainless steels, in the hands of competent welders, has reached a high stage of perfection in the last few years, welding engineers are by no means satisfied, and new methods and better welds are in the offing. The greatest chance for development will, unquestionably, be in the automatic welding field, and the result will be a more perfect blending of the weld and the parent metal. Of course, the field for automatic welding will apply principally to plate fabrication and, since time is a great factor in determining the cost of such work, shops using automatic welding machines should be able to materially lower welding costs over corresponding manual welding.

The acme of perfection has not, as yet, been reached in stainless austenitic steel products. In our experience we have found many cases where the cast product is superior to the rolled form, but since corrosion is a rather peculiar process it would not be unreasonable to assume that the reverse might prove true under other circumstances. Resembling a cast structure somewhat, perfect welds are very often superior in corrosion resisting qualities to the plates they join.

The preparation of this paper has been materially aided by the helpful criticism and valuable data given to the author, not only by our own welding and engineering staff, but also by Mr. Joseph Grimes of the Steel Tank and Pipe Company of Portland, Oregon.

THE TRAINING OF WELDERS in a Technical High School

By B. E. OTT†

IN AN industrial city like Detroit, welding is required in nearly every manufactured product, e.g., automobiles, refrigerators, beer barrels, furniture, etc. In an endeavor to meet this demand, Cass Technical High School of Detroit, Michigan, is doing a satisfactory job.

Instruction in welding is given in the evening school classes to approximately 225 students each term of twelve weeks duration. There are four of these terms in a year which means between 800 and 1000 men are trained in one year for the welding industry. However, a man must attend school from one and a half to two years to complete fully the entire course.

Some of these students, having discovered that they are not fitted for the job or do not like the work, drop out of the classes after a term or two in attendance. In many cases men who have completed one term go into production work in factories.

The men are given two hours twice a week in actual welding practice, this includes oxyacetylene, spot and arc welding. They are also given one hour twice a week in welding theory and metallurgy.

The fee charged is $6.75 for a term of twelve weeks, including welding theory and metallurgy.

The shop equipment includes twenty-six sets of oxyacetylene welding equipment, two portable sets of gas welding equipment that may be moved about for welding purposes outside the room, one spot welder and eight different types of arc welders.

The men are taught how to set up oxyacetylene welding equipment. After they understand the adjustment of the torch, they are then taught to weld by different types of exercises which will teach them the following essentials of welding:

1. Puddling (by this exercise the student is taught the manipulation of the torch, the actual torch movement that is desired for a trained welder), Fig. 1.
2. Puddling two pieces of metal together without a filler rod.
3. Laying a bead with filler rod on sheet metal.
4. Inside corner fillet welding, Fig. 2.
5. Welding two pieces together with filler rod, Fig. 3.
6. Outside corner welding.
7. Lap welding.

(The above exercises are done on a horizontal surface; then the same exercises are done in a horizontal position on a vertical surface; and vertically on a vertical surface and in an overhead position.)

8. Pipe welding in all positions.
9. Use of the cutting torch.
10. Welding solid rods.
11. Brazing steel.
12. Brazing cast iron.
13. Brazing steel to cast iron.
14. Welding cast iron.
15. Welding sheet aluminum

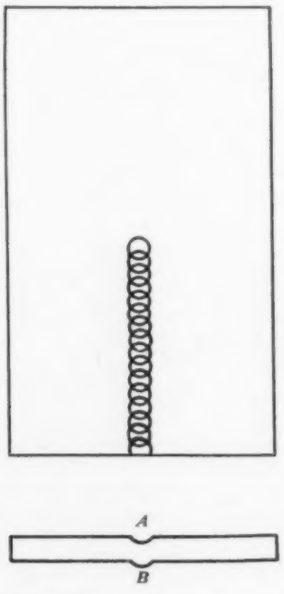


Fig. 1—Puddling

A—Puddle
B—Bottom of Puddle

† Head Auto-Aero Dept., Cass Technical High School.

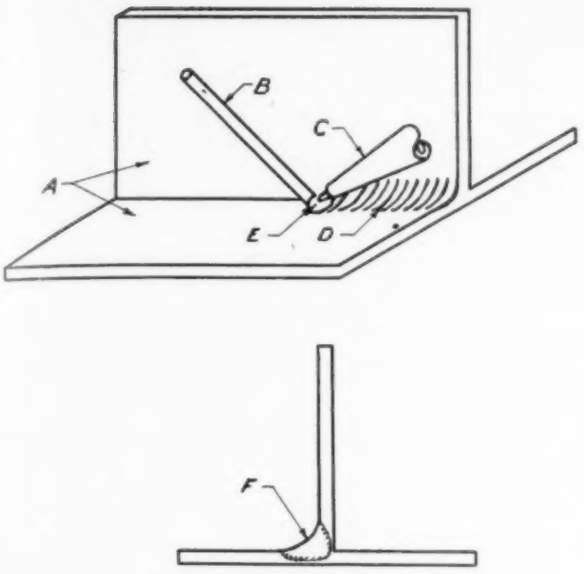


Fig. 2—Inside Corner Fillet Welding

A—Cold-Rolled Steel
B—Filler Rod
C—Torch Tip
D—Weld
E—Molten Metal

16. Preheating and welding.
17. Many special jobs such as: Thermit welding, white metal spraying, atomic hydrogen and spot welding.

After being given instruction in the adjustment and use of various arc-welding machines, the following exercises are presented:

1. Run a bead.
2. Butt weld two pieces together.
3. Lap weld.
4. Inside corner fillet weld.
5. Cast iron with steel.
6. Cast iron with carbon arc.
7. Cutting with carbon arc.
8. Vertical welding.
9. Horizontal welding.
10. Overhead welding.

The welding theory and elementary metallurgy that is taught comprises the information listed below:

1. Safety rules.
2. Gas welding.
3. Electric welding.
4. Blast furnace.
5. Bessemer converter.
6. Open-hearth.
7. Mechanical treatment of steel.
8. Alloy steels.
9. Weldability of metals.
10. Welding flux and rods.
11. Testing of welds.
12. Elementary metallurgy.

The demand is steadily growing for welders both in production work and pipe-line work, in the oil and gas fields. The demand for this type of instruction in Detroit is steadily increasing, as evidenced by the fact that there is a waiting list of 150 to 200 men all the time for enrolment in the welding classes offered in Cass Technical High School of Detroit.

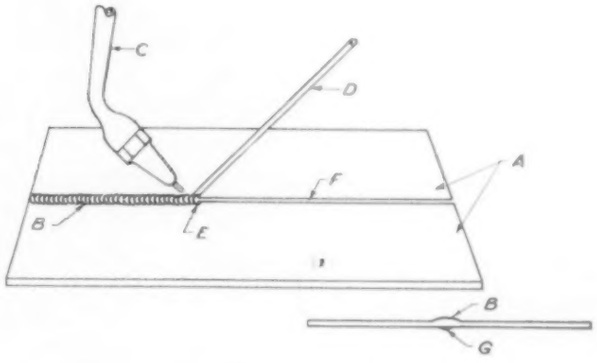


Fig. 3—Welding Using Filler Rod

A—Cold-Rolled Steel
B—Weld
C—Torch
D—Filler Rod
E—Molten Metal
F—Space Between Parts
G—Penetration of Weld

DRILLING and DISINTEGRATING

Heavy Concrete with Oxygen Lance

By M. R. SEMMER†

"FIRE Eats Through Wall Seven Feet Thick" so headed "Today's Picture Story" in the Pittsburgh Press of October 17, 1937. The picture story related to the burning of a hole for a pipe line through a $7^1/_2$-foot solid concrete wall of the Liberty Automobile Tunnels, Pittsburgh.

In laying the 4-inch emergency water pipe line, which is to be used in case of fire and also in washing out the tubes, the——&——Plumbing Contractors, who were doing the work, found that they were stymied when they ran into the $7^1/_2$-foot solid concrete wall which they originally thought to be a hollow partition.

For six hours their crew of three, using star drills and sledge hammers, chipped away at the wall and at the end of the day had penetrated but 12 inches into the concrete. The further into the concrete they chipped, the harder the job became because of the difficult and cramped positions under which the work had to be done. At this point, the contractors called the writer in for consultation. After inspecting the job, it was decided that it would be next to impossible to chip through the wall even if they worked from both sides.

† Pittsburgh District, Air Reduction Sales Company.

Fig. 1—Set-Up of Oxygen Lance with Regulator and Oxygen for Disintegrating Concrete

While with AED in 1926 a similar experience was met in dismantling a section of the old Sharon Brewery in Sharon, Pa. They were pulling out heavy concrete machinery foundations in order to make space for a cold storage room. These foundations were approximately 6 feet wide, 9 feet long and 3 feet high with twelve foundation bolts imbedded in each. This was the writer's first experience in disintegrating concrete with heat. Dynamiting on this job and also the Liberty Tunnels was impractical because of damage that would result to other parts of the building or tubes.

On the Sharon job the writer attempted to burn out the foundation bolts with the oxygen lance. This of course

Fig. 2—Hole Started in Concrete Wall by Sledging with Star Drills, and Finished by Disintegrating with the Oxygen Lance

is no unusual job and something that every welder can do. But the discovery that was made on that job proved an invaluable experience. It was this knowledge that solved the problem in the Liberty Tunnels. After burning out the foundation bolts at the brewery, it was discovered that the concrete which was affected by the heat would chip off in large pieces when hit with a hammer. This proved that the temperature required to melt iron, steel and similar metals will disintegrate concrete. By applying heat to the rest of the abutments, the brewery concrete foundations were quickly leveled.

The following method was used on the Liberty Tunnels project: We started the lancing operation in the concrete wall where they had chiseled a hole about 10 inches in diameter and 12 inches deep. Into this hole we placed metal scrap and heated the metal to the molten stage, which was approximately 2500° F. This same temperature disintegrated the concrete surrounding the metal. By continuing this process of feeding steel scrap, and applying the lance, the hole became deeper and deeper. As the concrete was penetrated by the oxygen lance, the molten metal carrying disintegrated concrete oozed like lava from the hole. It was forced out in a comparatively steady stream by the pressure of the oxygen at the closed end of the hole. It took seven hours to do this job. A hole approximately 4 inches in diameter was bored

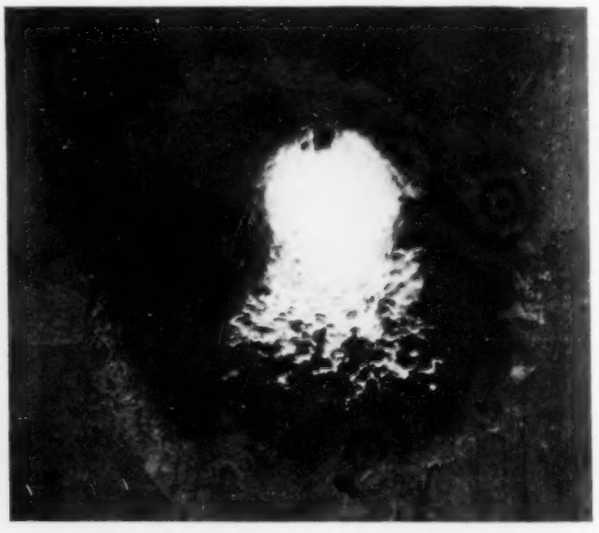


Fig. 3—Appearance of Hole in 7½-Foot Concrete Wall as the Concrete Was Being Disintegrated by Heat of Melting Steel Scrap

through 7½ feet of concrete wall with the oxygen lance at the rate of one foot per hour. 1430 cubic feet of oxygen were used. Apparatus and supplies used on this application were:

One oxygen regulator, 50 to 60 pounds pressure.

Twenty-five 5/16-inch green hose and connections to fit 3/8-inch pipe.

Eighteen 20-foot standard lengths of black iron pipe.

1430 cubic feet of oxygen.

The MAINTENANCE and REPAIR of Heavy Construction Equipment*

By T. B. JEFFERSON†

WELDING is becoming an indispensable tool for those engaged in construction work. For years, welding has been considered primarily a tool for fabrication, but more recently it has been recognized as a tool for maintenance and repair of equipment.

At Fort Peck, Montana, where the Army Engineers are building a hundred million cubic-yard hydraulic-fill dam across the Missouri River, welding is used extensively in the repairing plant. This extensive use came about for two reasons. One was the fact that the project is a considerable distance from a ready source of supply. The other is that welding, in some cases, offers an appreciable saving in the reclamation of machinery.

Practically every known type of excavating machine, from the lowly head shovel to the large electric dredges capable of excavating 2500 cubic yards of material per hour, has been used in connection with building this huge project. Many other items which come under the category of heavy contracting equipment, such as tractors, locomotives, cranes, concrete mixers and similar pieces of machinery, are used in addition to the excavating equipment. The steel and other metallic parts in all of these machines are exposed constantly to those destructive forces which wreak havoc with metals. When machines are being operated, their parts are constantly subjected to abrasion, impact and fatigue; and when stopped, to corrosion. As a result, the parts of these machines rust, wear, break and require replacement. Replacement may be obtained from two sources, either by purchasing new parts or by reclaiming used parts.

As breakdowns are sudden and replacement parts were not always available, welding at first was used for emergency repairs. These repairs were considered as a temporary measure only—something that would permit the equipment to operate until new parts were received. However, it was found, in some cases, that when such repairs were made by a capable welder, the reclaimed parts were as good as new and their replacement by new parts was unnecessary.

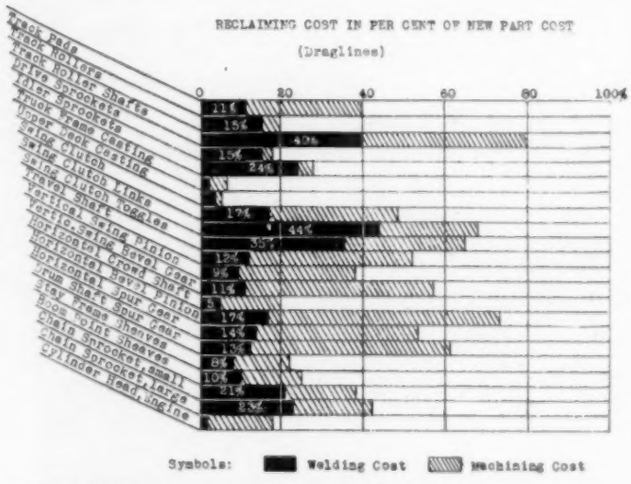


Fig. 1—This Chart Is a Tabulation of the Cost of Reclaiming Parts Instead of Purchasing New Parts for the Repair of Draglines. This Illustrates the Cost on a Particular Job and Should Not Necessarily Be Considered as an Average Cost for This Type of Work

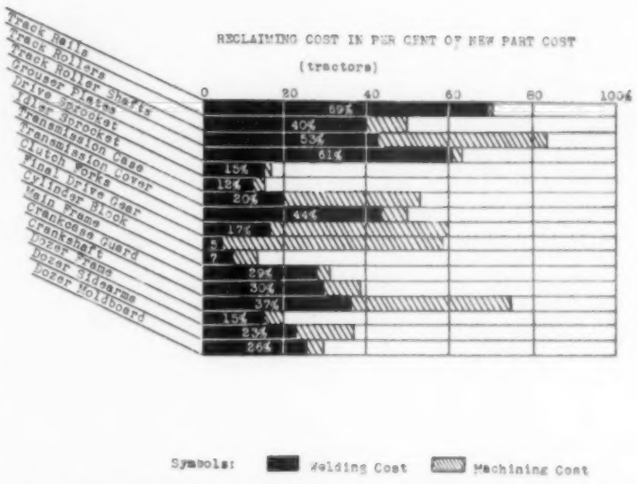


Fig. 2—While the Cost of Reclaiming Tractor Parts Is Higher Than the Costs Just Shown for Draglines; Quite a Saving Is Made Possible by This Method of Obtaining Repair Parts. This Chart Also Shows Cost of an Individual Job Rather Than an Average Cost

The equipment required for making repairs by either the oxyacetylene or electric-arc welding process is small, and therefore, easily portable. This feature makes it possible, when using welding for making repairs, to literally take the shop to the job rather than bring the job to the shop. Through this procedure, much time is saved and shutdowns are reduced to minimum. The economy by this method is obvious.

Even more time can be saved in making repairs by welding, when it is possible to make the necessary repairs without dismantling the machine. An example of this may be cited by referring to the repairs which were made to a Diesel crawler-type tractor. On this particular tractor the drive sprockets, the track pins and bushings had become so badly worn that the machine frequently "jumped the track." Such wear presents no particular problem until it has become so great that the slack cannot be removed by further adjustment of the track release springs. When this condition occurs, usually it becomes necessary to replace the sprockets and either replace or rebush the tracks, to prevent further production delays due to "track jumps."

It is obvious that delays in operation are primarily of more importance to a contractor than the actual cost of repairs, unless the latter is unusually high. As a rule, the cost of repairing a piece of equipment is of concern only to the master mechanic, because his reputation is

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* Presented at Western Regional Conference, A. W. S., Los Angeles, March 21–25, 1938.

† Associate Engineer, U. S. Engineer Office, Fort Peck, Montana.

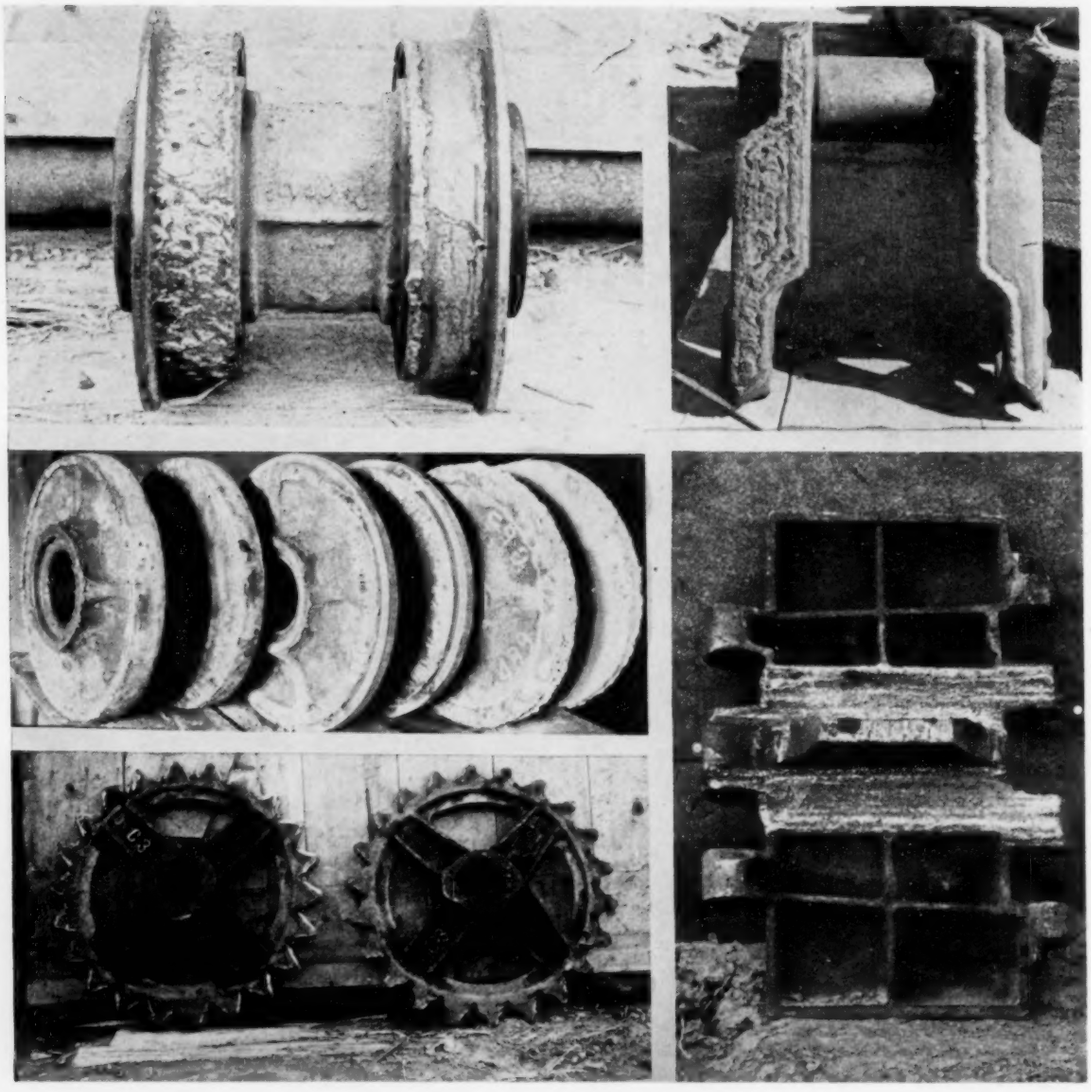

Fig. 3—Two Steps Are Required in the Reclaiming of Tractor Track Rollers by Welding. The First Involves the Running of a Guide Bead of Proper Height Around the Inner Edge of the Tire. The Tire Is Then Rebuilt to Its Original Height by Depositing Weld-Metal Between the Guide Bead and the Flange

Fig. 4—A Guide Bead Is Also Used in Controlling the Height of the Weld-Metal Deposit in the Rebuilding of the Track Links or Rails of the Crawler Type Tractor

Fig. 5—These Three Rollers Illustrate the Progressive Steps in Reclaiming Dragline Track Rollers. The Worn Roller on the Left Is Approximately One Inch Undersize. Reclamation Is Being Expedited by the Use of Steel Bar Rings as May Be Seen on the Center Roller. The Right-Hand Roller Has Been Completely Reconditioned by Welding

Fig. 6—Dragline Track Pads Are Reclaimed by Replacing the Metal Which Has Been Worn from the Roller Path and by Rebuilding and Remachining the Connecting Pin Eyes

Fig. 7—These Two Dragline Drive Sprockets Illustrate the Manner in Which Welding Is Used for Repairs. On the Left Is the Reclaimed Sprocket While on the Right Is Pictured the Worn Sprocket. Note the Wear on the Teeth

judged principally by this record. However, when a machine breaks down on the job, resulting in a serious operating delay, but with continuing operating cost, everyone is concerned. When production stops and operating costs continue, the profits of the job are reduced and penalties sometimes incurred, thus creating a serious situation, since the continuance of an organization depends upon the profits realized on its jobs.

Repairs, in the case of the above-mentioned tractor, could be made either by replacing all of the worn parts, which would necessitate the removal of the machine from operation for several weeks, or by reclaiming the worn parts by welding. With the latter plan in mind, a welding operator, with the necessary equipment, was dispatched to the idle tractor. After the tracks were removed from the machine, he was ready to start reclaiming the worn parts. As the rebuilding of each of the track pin bushings would have necessitated disassembling the track, it was decided to do all of the reclamation in connection with the drive sprocket. Rather than replace the material, which had been worn approximately $^1/_4$ in., it was decided to weld metal inserts in each worn pocket between the sprocket teeth. This was accomplished by welding semi-circular segments between each tooth. These segments were obtained by cutting rings from 4-in. pipe and then cutting each ring in half. By this procedure, the entire job was completed for only 15 per cent of the cost of new drive sprockets.

Throughout this article, the cost figures will be indicated as a percentage of the cost of the reclaimed part compared to the cost of a new part, as actual cost figures would be of interest only to those operating such equipment. For a similar reason, no attempt will be made to go into the technical details of welding procedure applying to a particular job.

It is possible to reduce the cost of some parts used in

the complete overhaul of a dragline or shovel from 60 to 75 per cent, by the use of reclaimed parts. Such a saving naturally reduces the cost of the entire overhaul job. As it usually is impossible to anticipate all the repair parts that will be required for a specific job, an overhaul program that contemplates reclamation of parts affords an even greater saving. Frequently it has been found, when dismantling a machine, that parts appearing in good condition while the machine is assembled, in reality, are worn beyond further use without repair. If welding is used in reclaiming parts, however, these parts may be reconditioned without causing the delays that might have been incurred had it been necessary to purchase new parts.

Welding cannot be considered as the only operation necessary in reclaiming parts. Nearly every part which is reconditioned by welding also requires machining. The outstanding exceptions to this rule are the sprockets and rails used on the crawler-type tractors and the track rolls of the crawler-type shovels. Whether the part is reclaimed by welding or by a combination of welding and machining, the cost of the completely reconditioned part is usually much less than that of the new part. An example of reclamation of parts, by the combined use of welding and machining, may be seen in reclaiming a worn shaft. When a repair of this nature is made, the worn shaft is first sent to the machine shop; while there, the shaft is machined down so that it has a uniform diameter. The shaft is then sent to the welding shop, where it is built up oversize and returned to the machine shop for remachining to the proper size.

A typical example of the use of welding in the maintenance of equipment at Fort Peck is as follows: Recently, during an overhaul, two Diesel shovels received 25 different welding applications. This does not mean that only 25 pieces were welded, as many of these applications were repetitions; for example, each of 68 track pads, three cracked cylinder heads, ten track rollers, etc., were reclaimed. It was determined, after dismantling both of these shovels, that it would be necessary to rebuild the center pin hole in the truck-frame casting. On this occasion, it would have been necessary to purchase a new truck frame casting and a new center pin, the cost of which would have been considerable. The truck-frame casting was rebuilt, however, by welding. It was not necessary to rebuild the center pin, since it could be machined slightly undersize, and the center pin hole in the truck-frame casting could be machined to fit the pin after the hole had been rebuilt. The saving on a repair of this nature is obvious, since these parts represent a large portion of the original cost of the shovel. The use of welding in the repair of these same machines, for reclamation of parts, has made it possible to obtain replacements at only a small percentage of the cost of new parts. For example, track pads, track rollers, drive sprockets, idler sprockets, roller shafts and cylinder heads may be reconditioned for less than the cost of new parts. There were many other items, such as gears, shafts, cases and other parts too numerous to mention, on which welding was used. Past experience has shown that, in most cases, where a part was reclaimed, it was equal in every respect to a new part. Attention is invited to the fact that judgment should be used in deciding which parts should be reclaimed by welding and which should be replaced with new ones.

The variety of repairs to other types of heavy construction equipment is similar to those experienced in the rebuilding of a shovel. A crawler tractor, overhauled recently, was found to have a drive case that was cracked in several places. It was necessary to preheat this cast-iron case (weight 3000 lb.) before repairs could be undertaken. After the repairs had been made by brazing, it was necessary to perform extensive machining, to re-align the many bearings and shafts housed in this assembly. Despite these difficulties, the case was completely reconditioned for less than 50 per cent of the cost of a new one.

It has been found, in connection with the building of the Fort Peck Dam, that welding equipment in the hands of a skilled operator can easily turn the most difficult job into a routine task. The flexibility of welding makes it a versatile, all-purpose tool which, through its unlimited number of applications, presents opportunities for remarkable savings to the operators of heavy contracting equipment. On a visit to the U. S. Engineer Shops, it is not at all unusual to see a welder replacing a broken tooth from a gear or increasing the wear-resisting qualities of a bucket tooth or a dipper lip by hardfacing.

Hard-facing is now being applied to parts which are subjected to wear, as well as parts used for cutting and scraping. These parts include grouser plates, track and track rollers, grader blades, ripper teeth and scraper lips. This extensive use of hardfacing has been brought about by the increase in the life of wearing surfaces, made possible by the use of hard-metal applications. Likewise, it has been found that if correctly applied, hard-facing will keep the edge of a cutting blade self-sharpening. The cutting edge of an excavating machine that will sharpen itself will not only do more efficient work, but will require less attention, eliminate frequent resharpening, and also reduce the power required to pull such a part through its working medium.

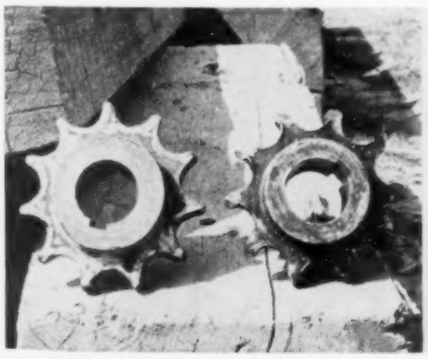

Fig. 8—Small Gears and Sprockets Are Reclaimed by Welding and Are Then Remachined. The Drive Chain Sprocket on the Left Has Been Reconditioned While Its Companion Sprocket on the Right Pictures How Badly They Had Been Worn

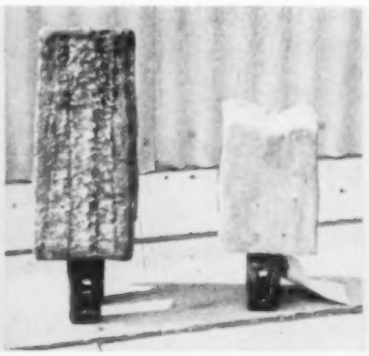

Fig. 9—Dipper and Bucket Teeth Are Reconditioned and Repointed by Welding. They Are Also Hardfaced for Greater Resistance to Abrasion

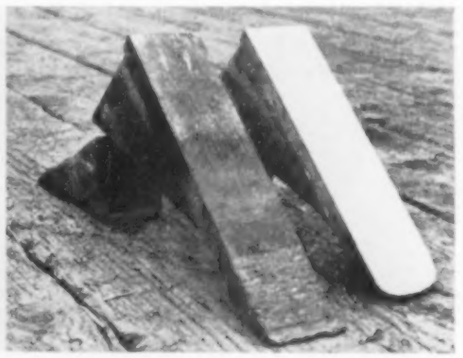

Fig. 10—Ripper Teeth Which Have Been Hardfaced Last Longer and Pull Easier

AN APPROXIMATE METHOD

for Calculating the Distortion of Welded Members*

By G. J. GIBSON†

ARC welding shrinks and distorts steel members because the thermal expansion resulting from the steep temperature gradient of the concentrated heat of the arc exceeds the elastic resistance of the surrounding metal. A certain volume of the base metal upsets so that when this upset metal cools, it tends to shrink to a smaller area than it occupied before it was heated and upset by the arc. The shrinkage of this area tends to take place in all directions, but since the arc travels in a straight line the upset metal consists of a band on either side of the path of the arc. Shrinkage can be classified in two types: transverse shrinkage or shrinkage across the weld, and longitudinal shrinkage which occurs along the direction of the weld.

Transverse shrinkage is that which causes welded joints to close, and causes angular distortions of the members at the weld. Transverse shrinkage is troublesome when the plates being joined are fixed; otherwise practically no shrinkage stresses and distortions would result except when the member being welded is only welded on one side, when there might be angular distortion. When there is not enough heat from the arc to upset the entire thickness of the plate, the unaffected section of the joint will resist the shrinkage of the upset portion and an angular distortion of the joint will result. Longitudinal shrinkage stresses are always present along the weld. Shrinkage along the weld is resisted elastically by the metal on each side of the weld producing a condition of uniform strain and subsequent stress. This condition essentially consists of a certain area of metal about the weld stressed in tension and resisted by compression in the rest of the section. Welds will cause small changes in length of the section being welded, but if the welds are not balanced or are unsymmetrical with the center of gravity of the section welded, the longitudinal shrinkage will cause distortions. This paper presents an approximate method of quantitatively evaluating distortion of members resulting from longitudinal shrinkage.

SHRINKAGE DISTORTION OF WELDED MEMBERS

A welded member is assumed to be a beam, H section, or a built-up member; so that, if any welding is done on one part, the shrinkage of this part due to the heat of the welding is resisted elastically by the rest of the member. A piece of steel completely fixed at its ends will be stressed up to its yield point by its thermal expansion for only about 100° C. temperature rise. Any further rise in temperature will cause the metal to yield and upset. If the piece was upset sufficiently, say by an expansion of equal to or greater than its elastic strain up to the yield point, on cooling it will have a residual stress in tension equal to its yield point. This is because on cooling it will try to recover the total thermal change but if the length of the piece lost in upsetting corresponds to a deformation greater than the yield-point stress, a yield-point stress in tension will result.

Thus, when welding on a member, the heat of welding will cause a certain area of the section about the weld to be upset because the thermal expansion in this area will be resisted by the rest of the section, and this upset area, when cooled, will have tension stress equal to the yield point. This residual tension is the force that distorts the member. This force is peculiar in that it is internal and it must be resisted by compression in the rest of the section. The algebraic sum of the tension and compression forces at a section must be zero and their static moment about any point must also be zero.

Experiments made by Boulton and Martin[1] with a plant specimen welded along one long edge illustrate the shrinkage action of the weld very clearly. A bead of

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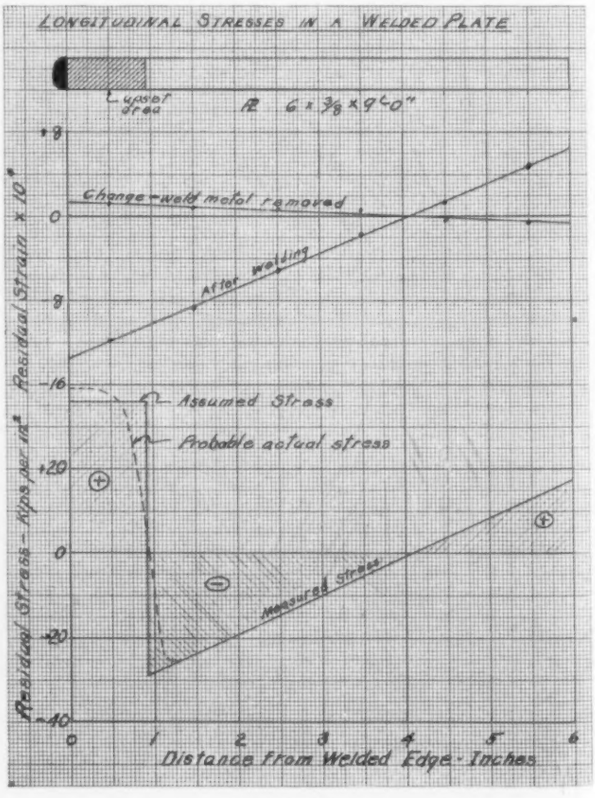

Fig. 1

Abstracted from Technical Bulletin No. 3307 Research Department, Pittsburgh-Des Moines Steel Co.

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weld-metal was deposited continuously along one long edge of a plate, 6 in. x 3/8 in. x 9 ft. 0 in.. Strain-gage readings were taken in the middle section of the plate in the direction longitudinal to the weld and the results are plotted in Fig. 1.

The strain distribution in the plate follows a straight line with the maximum shrinkage at the welded edge changing to expansion at the far edge. The strain measured close to the weld is no indication of the stress because the metal in this section has been deformed plastically, and is actually stressed in tension as shown in the stress diagram. The only way to determine the stress in the upset area is to cut out sections and measure their elastic recovery. When the weld-metal only was removed by machining it relieved very little of the deformation of the plate. This fact shows that practically all deformation caused by welding is due to the upsetting of the base plate by the heat. After removing 1.1 in. of the plate on the side of the weld the remainder of plate returned to its original shape with no locked-up welding stresses. In other words the upset area extended about 1 in. from the edge of the plate. This simple example shows the basic principle of shrinkage action and serves as a guide in making assumptions in more complicated shrinkage problems.

The upset area is assumed to have a rectangular section when it extends to the edges of the plate. The change of stress from tension in the upset area to compression in the unaffected plate is assumed abrupt because the effective upset area has definite limits and the maximum resistance should be nearest the load. The deformation is based on the elastic resistance in compression which depends primarily on the magnitude of the shrinkage forces. Tests were made to determine the extent of the upset area for any size of weld deposited.

The amount of heat required to deposit a pound of weld-metal is approximately a constant regardless of the size of electrode or the welding current used. The area of base metal upset depends on total heat induced into the plate. If the weld is made up of more than one pass the effect of each bead will be an increase of the upset area in the plate.

A series of tests were made to determine the area upset for a given weight of deposited weld-metal. Various sizes of beads were deposited on the long edges of 8 x 2 x 12 in. plates. Strain-gage readings were taken on both sides of the plates to measure their change in length parallel to the welds. The resultant compressive stress between the two upset areas will be uniform as shown in the sketch of the stress diagram (Fig. 2). The strain-gage readings measure the shrinkage and the compressive stress in the plates caused by the tension in the upset area.

Total tension in upset areas = total compression in plate

a = upset area of one bead

30,000 lb. per in.^{2} = assumed yield point tension stress in the upset area

$30{,}000 \times 2a = (16 - 2a)$ (compressive stress)

Thus, the upset area can be computed and the results are tabulated as follows:

Electrode Size	Shrinkage in 8-Inch	Wt. per Foot of Bead Lb.	Upset Area In.	Area Upset per Lb. of Weld per Ft. of Bead
3/16	0.0004	0.082	0.38	4.6
1/4	0.0006	0.166	0.57	3.5
5/16	0.0019	0.287	1.55	5.4
1/4	0.0024	0.700(4 beads)	1.85	2.7

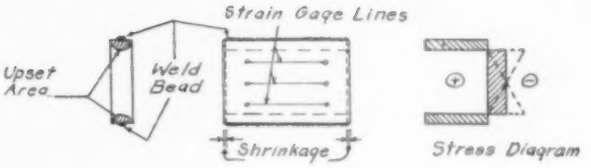

FIG. 2

TEST SPECIMEN FOR DETERMINING UPSET AREA

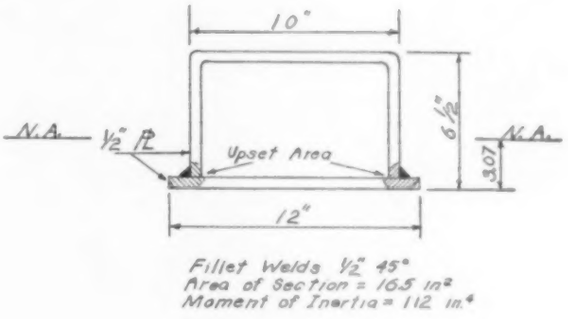

FIG. 3

MEMBER USED FOR COMPUTING WELDING DISTORTION

The compression stress in the plates was determined from the shrinkage observed by the strain gage assuming the strain was uniform over the gage length and the stress was less than the yield point. The weight per foot of bead was taken as the weight of electrode melted in depositing a foot of bead. The resulting upset area per unit size of weld shows a considerable variation for an assumed constant. The area upset per unit of weld is proportionally greater for one pass of a 5/16-electrode and less for welds made up of a number of beads. Since many other variables affect the size of the upset area, it is well within the error of application to use a round figure of 4 sq. in. per pound per foot of weld for single-pass welds and 3 sq. in. upset per pound per foot of welds made up of multiple beads. These figures check fairly well with the available experimental data in the literature.

All applications of the upset metal theory depend primarily on the upset area and secondarily on the distribution of the stresses resisting the shrinkage. No attempt is made to determine the shrinkage of wide thin plates because the distribution of the stresses is probably very complex and thin plates cannot resist much compression without buckling. The chief difficulty in application of the principle results from the unsymmetrical distribution of the shrinkage stresses across the section, which is further complicated by any structural restraint at the ends of the member. A weld longitudinal to the member will shrink it uniformly along the length of the weld. A weld transverse to the member will shrink it in length only across the width of the upset area. Unsymmetrical longitudinal welding on a member will cause it to bow uniformly along its length, while unsymmetrical transverse welding will cause a sharp angular change of the weld. The next two sections will illustrate these points.

SHRINKAGE TESTS

Beads of weld-metal from different sized electrodes were run across the outside of both flanges of wide flange

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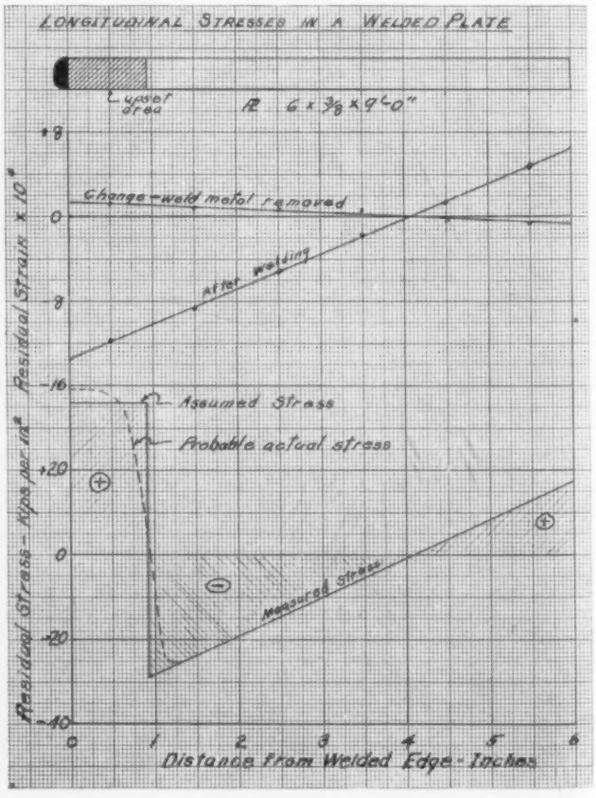

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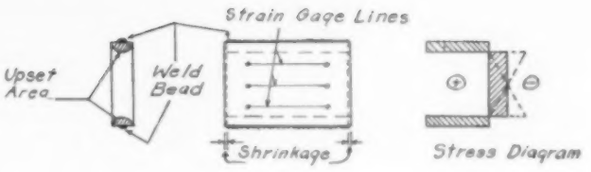

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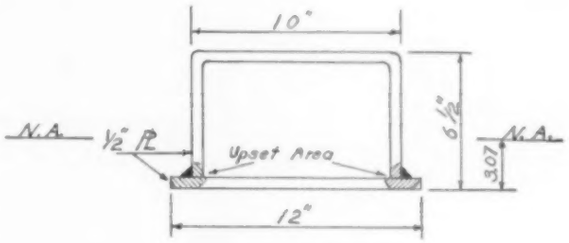

Fillet Welds ½" 45°
Area of Section = 16.5 in.^{2}
Moment of Inertia = 112 in.^{4}

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MEMBER USED FOR COMPUTING WELDING DISTORTION

The compression stress in the plates was determined from the shrinkage observed by the strain gage assuming the strain was uniform over the gage length and the stress was less than the yield point. The weight per foot of bead was taken as the weight of electrode melted in depositing a foot of bead. The resulting upset area per unit size of weld shows a considerable variation for an assumed constant. The area upset per unit of weld is proportionally greater for one pass of a $^5/_{16}$-electrode and less for welds made up of a number of beads. Since many other variables affect the size of the upset area, it is well within the error of application to use a round figure of 4 sq. in. per pound per foot of weld for single-pass welds and 3 sq. in. upset per pound per foot of welds made up of multiple beads. These figures check fairly well with the available experimental data in the literature.

All applications of the upset metal theory depend primarily on the upset area and secondarily on the distribution of the stresses resisting the shrinkage. No attempt is made to determine the shrinkage of wide thin plates because the distribution of the stresses is probably very complex and thin plates cannot resist much compression without buckling. The chief difficulty in application of the principle results from the unsymmetrical distribution of the shrinkage stresses across the section, which is further complicated by any structural restraint at the ends of the member. A weld longitudinal to the member will shrink it uniformly along the length of the weld. A weld transverse to the member will shrink it in length only across the width of the upset area. Unsymmetrical longitudinal welding on a member will cause it to bow uniformly along its length, while unsymmetrical transverse welding will cause a sharp angular change of the weld. The next two sections will illustrate these points.

SHRINKAGE TESTS

Beads of weld-metal from different sized electrodes were run across the outside of both flanges of wide flange

beams. The shrinkage in length of the beam across the welded section was measured with an 8-in. strain gage. The beam used in the first test recorded in the table had the following dimensions: d = 12 in., web thickness $^5/_{16}$ in., flange width 8 in. and $^1/_2$ in. thick. The beam used for the remainder of the tests was 12 in. deep, web thickness $^{13}/_{32}$ in., flange width 12 in. and $^5/_8$ in. thick. The weight per foot of bead was determined from the length of electrode melted, and the welding current was the average usually used for each size of electrode.

The method of calculating the shrinkage is emperical because on taking a section of the beam through the welds, it can be seen that the full thickness of both flanges are upset and the shrinkage stresses in the flanges will cause the web to yield along a distance equal to the width of the upset area. This reasoning is followed in the following sample calculation:

1 pass across each flange of the 12 x 12-in. beam with $^1/_4$-in. electrode
Wt. per foot of bead = 0.129 lb.
0.129 × 4 = 0.516 sq. in. upset area perpendicular to weld
4 = area upset per lb. per ft. of weld
Depth of upset area is equal to thickness of flange.

The width of upset area $= \frac{0.516}{^5/_8} = 0.825$ in. and is the distance along which the beam shrinks.

Since the flanges and web both yield, the shrinkage would be proportional to a ratio of their areas, and 0.10 per cent is the elastic shrinkage from the yield point.

$$0.825 \times 0.001 \times \frac{15}{3.55} = 0.0035\text{-in. shrinkage in length of beam}$$

Electrode Size	Wt. of Bead per Ft.-Lb.	Upset Area In.²	Width of Upset Area	Calculated Shrinkage In.	Measured Shrinkage In.
$^5/_{32}$	0.065	0.26	0.52	0.0012	0.0010
$^3/_{16}$	0.096	0.39	0.61	0.0026	0.0029
$^1/_4$	0.129	0.52	0.83	0.0035	0.0036
$^5/_{16}$	0.287	1.15	1.85	0.0077	0.0114

The constant of 4 sq. in. of upset area per lb. per foot of weld is too low for the $^5/_{16}$-in. electrode as was also noted in the plate shrinkage tests.

THEORETICAL EXAMPLES OF SHRINKAGE STRESS AND DISTORTION

The longitudinal shrinkage of the two welds shown in Fig. 3 will distort the member because the welds do not coincide with the center of gravity of the section.

Shrinkage Stresses

$^1/_2$-in. 45° fillet-area = 0.125
Upset area = 0.125 × $^3/_4$ × 4 = 1.7 in.²
Total upset area = 3.4 in.² (2 fillets)
Total shrinkage force = 3.4 × 30,000 = 102,000 lb.
Tension—assume located at the inside face of the cover plate
The induced moment = shrinkage force × eccentricity with the c.g. of the section
M = 102,000 × 2.57 = 262,000 lb.

Since the shrinkage forces are unsymmetrical, the member will act like an eccentrically loaded column.

$$\text{Fiber stress} = \frac{P}{A} \pm \frac{Mc}{I}$$

$$= \frac{102{,}000}{(16.5 - 3.4)} \pm \frac{262{,}000c}{112}$$

+ 200 lb./in.² on the side opposite cover plate
− 15,000 lb./in.² in the cover plate.

Distortions

Consider a straight piece 20 ft. long. The shrinkage in length measured along the center line:

$$= \frac{7800 \times 20 \times 12}{30{,}000{,}000} = 0.0624 \text{ in. (negligible)}$$

$$\text{Camber Middle ordinate} = \frac{ML^2}{8EI} \text{ for a constant } M$$

$$= \frac{262{,}000 \times 144 \times 400}{112 \times 30{,}000{,}000 \times 8}$$

= 0.524 in. which will be noticeable

Consider both parts of the member formed to a half-ring 20 ft. diameter with the cover plate inside and then welded. The shrinkage will close it to a smaller diameter because the welds are inside the center of gravity.

The chord for half a circle is equal to the diameter and it would shorten by the amount (x).

$$x = \frac{ML^2}{2EI} = \frac{262{,}000 \times 144 \times (10 \times 314)^2}{2 \times 112 \times 30{,}000{,}000}$$

x = 5.5 in. which is a serious distortion when the member is required to make a fit

CONCLUSION

It is possible to approximately calculate the shrinkage distortions of certain welded members; however, considerable experimental work is needed to more closely determine following factors:

1. The effective upset area for different sizes and types of electrodes.
2. The effect of multiple pass welds.
3. The distribution of the resulting shrinkage stresses in various members.

WELDING CLASS I PRESSURE Vessels

By B. W. FARQUHAR†

THE welding of U-68 pressure vessels came about in a very unusual manner. Corrosion difficulties made it desirable to change from mild steel to four to six per cent chrome with one-half of one per cent molybdenum on the pressure still heat exchanger shells of the hot oil to gasoline vapor type. In this service mild steel shells lasted a maximum of 3500 hours. The four to six per cent chrome shells have lasted, to date, 7000 hours with no detectable loss by calibration. These four to six per cent chrome shells were built and normalized by an eastern fabricator. Upon inspection at the Port Arthur plant it was found that the longitudinal seam had developed transverse cracks at approximately three-inch intervals. X-ray pictures were taken to determine the extent of these cracks, and it will be seen from Fig. 1 that these cracks extended entirely through the welds. Since these shells were to be subjected to gasoline vapor at a temperature of 800° F., and a pressure of 100 lb. per sq. in., a vessel of this type could not be used.

† Gulf Oil Corporation, Port Arthur, Texas.

Fig. 1—Cracked Weld as Obtained from Fabricator

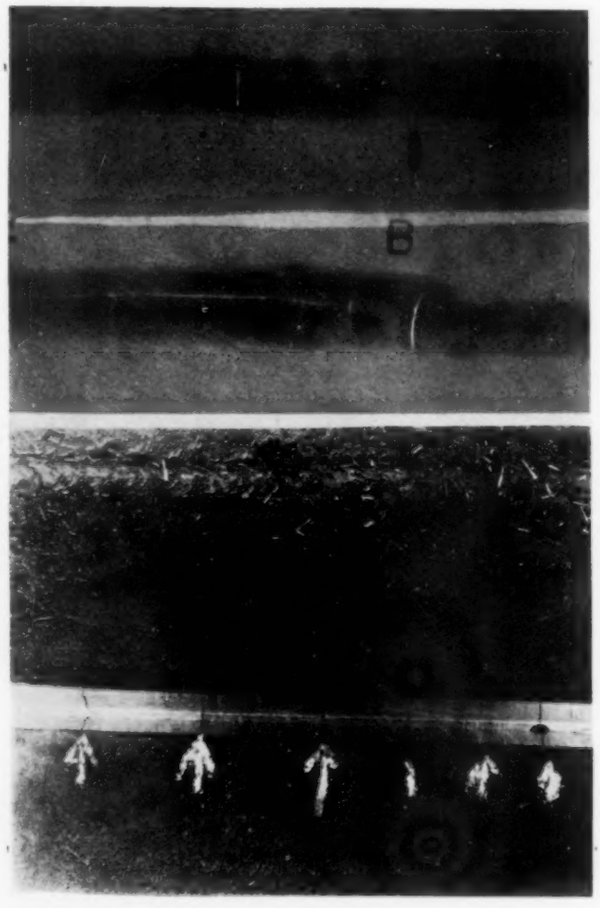

Fig. 2—Cracks That Extended Into Base Metal

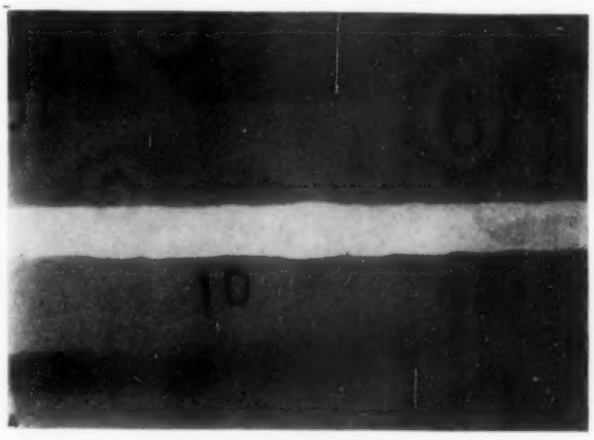

Fig. 3—Finished Weld

It was necessary to remove the old weld and that portion of the base material which was cracked by milling out the original weld. At first a V-type groove was made which would have rendered possible a minimum of weld-metal to be deposited, but upon examination cracks were found (see Fig. 2) to continue into the base metal at the root of the V. Since the diameter of the shell could not be changed and it was necessary to remove all of the cracked base metal a U-groove was used. After the weld had been made on the outside and normalized the U-groove on the inside was made to a depth of about $^3/_{16}$ inch by machine chipping.

This four to six per cent chrome with one-half to one per cent molybdenum steel in the "as-welded" condition has a Brinnell hardness number of approximately 400, and after heat treatment with stress relief at 1350; or a full normalize at 1550 has a Brinnell hardness number of about 175. The soaking time in the heat treatment furnace and the rate of cooling are the major factors in reducing the Brinnell hardness number of this material. The resistance to corrosion by hydrogen sulphide of four to six chrome with one-half of one per cent molybdenum makes it a material of great importance in the oil refining industry. Consequently, ways and means of fabrication must be found whereby it can be used to its greatest advantage.

Since this material is classified as an air-hardening material, preheating to a temperature of 400° with subsequent welding was found to be the most desirable procedure. Immediately after welding the vessels were placed in an annealing furnace with an initial temperature of approximately 600° F. and heated at the rate of 200° F. per hour until a temperature of 1350° F. was reached. At this temperature the vessels were soaked for a period of two hours and cooled at a rate of not

Fig. 4—Groove for Gasket and Tongue Built Up of Four to Six Per Cent Chrome with One-Half of One Per Cent Molybdenum

Fig. 5—Finished Shell

exceeding 75° F. per hour until a temperature of 900° F. was reached. At this point the heating was discontinued and the vessels were allowed to cool in the furnace.

Since these vessels were welded from both sides, or with a double U-groove, preheating for the inside weld was necessarily of a progressive localized type. In other words, two large heating torches were used and heating was begun at the center of the long joint and the heat increased by six-inch increments from the center thus maintaining the welded portion at approximately 400° F. as well as the increment preceding the welding operation which was back-stepped from the center toward each end. Heat treatment was again necessary.

After removal from the furnace the weld was ground so that a uniform amount of excess material was obtained on the outside of the finished vessels with a minimum of undulations of the weld surface. The inside was ground to the same thickness of the shell so that in assembling the heat exchanger the floating head would easily slide through the shell. This served a twofold purpose; one, that of finishing the inside of the vessels, and two, that of getting the surface of the weld in a desirable condition for the purpose of X-raying the weld (Fig. 3).

The welders who worked on these vessels were qualified according to the A. S. A. Standard for pressure piping on four to six chrome with one-half of one per cent molybdenum tubing.

The welding procedure for the longitudinal weld was for that of back-stepping each pass in six-inch increments in such a manner that the tie-in of the preceding pass was in the middle of the succeeding pass. The first pass was made with $^1/_8$-inch rod followed by five passes of $^3/_{16}$-inch rod. This was sufficient to produce an excess of approximately $^1/_8$-inch for the tubing test piece. However, for the heat exchanger shell more passes were necessary to get a desirable excess due to the width of the U-groove.

The end flanges and the nozzle flanges are of steel with the groove for the gasket and tongue built up of four to six per cent chrome with one-half of one per cent molybdenum (Figs. 4 and 5).

After machining all mild steel parts of the shell were well protected by approximately $^1/_8$ inch of four to six chrome.

It is thought that these shells of four to six per cent chrome with one-half of one per cent molybdenum are the first vessels of U-68 classification to be built in the State of Texas.

WELDING RIDES THE RAILS!*

HIGH-TENSILE steels for the construction of railroad passenger equipment reached a new level of use on American railroads when the new streamliners of the New York Central and Pennsylvania Railroads began their inaugural runs simultaneously from east and west terminals June 15th to pass another milestone in railroad travel.

The past three years have seen the use of these steels bring economic advantages to the railroads in the operation of freight equipment. Efforts in this direction have seen 16,000 freight cars constructed of these steels and now the operating advantages realized in freight rolling stock are rapidly being applied to passenger equipment on today's crack trains.

Several types of high-tensile products were utilized in the construction of these cars. Cor-Ten steel was used for car bodies, Man-Ten steel for structural parts, and stainless steel for decorative trimmings and kitchen equipment.

Original and Striking Conceptions in Beauty and Utility of Appointments, Fresh Color Harmonies and Unique Architectural Effects Will Be Introduced to the Traveling Public in New Dining Cars Built Specially for the Pennsylvania Railroad's Forthcoming Fleet of New East and West Blue-Ribbon Trains. Novel Seating Plans and Table Arrangements, Built-In Sofas, Diffused Lighting, and the Use of Unusual Veneers and Fabrics Create Within These Cars the Warm and Friendly Atmosphere of a Club or Restaurant of the Intimate Type. Built by the Edward G. Budd Mfg. Co. This Type of Car Is Constructed of Stainless Steel, Fabricated by the Shotweld Process, and Produces a Body Which Is Intrinsically a Continuous Rigid Metal Sheath

Streamlining with high-tensile steels is in keeping with the deluxe appointments which these trains offer to the public without any increase in fare. Greater strength and greater resistance to corrosion permit Cor-Ten steel

* Taken from a news release of the U. S. Steel Corporation.

The New Streamlined Twentieth Century Limited, New York Central's Super-Train, Snapped in Action Running at About 80 Miles an Hour During a Test Run on the Central's Main Line Tracks Along the Hudson River. It Is drawn by a New Type of Streamlined Hudson Locomotive, of 4700 Horsepower

to give substantial savings in weight through the use of thinner sections in car bodies.

As a result of a reduction of approximately one-third in weight of the complete train, the more efficient locomotive, and streamlining, New York Central expects its new Century to reduce fuel consumption by 10 to 15 per cent between Harmon and Chicago. Approximately 47 tons of coal are now burned on this run. Operating economies of the new streamliner are expected to show savings of from 5 to 10 tons of coal.

In the new trains, railroad travel will reach a new high in comfort and convenience. The new Broadway Limited and the Twentieth Century will be the first all-room trains in America, with Pullmans including various groups of roomettes, bedrooms, compartments, drawing rooms and master bedrooms.

In addition to these two trains, the Pennsylvania Railroad is introducing similar new equipment in three crack trains, operating daily in each direction between its eastern and western terminals—the General, the Liberty Limited and the Spirit of St. Louis. The new cars for these trains were built largely of Cor-Ten by Pullman-Standard Car Mfg. Co., although two Pennsylvania streamlined diners of stainless steel were constructed by Edward G. Budd Mfg. Co.

Fifty-two of these all-welded high-tensile steel cars, plus six diners and four baggage cars, will make up four sections on the New York Central's Twentieth Century crack trains, two in each direction between Chicago and New York. The 52 streamlined cars for the Pennsylvania will operate in its "Blue Ribbon" fleet, namely the Broadway Limited and the General east and west bound between New York, Philadelphia and Chicago; the New Spirit of St. Louis between the Seaboard and the Mississippi Metropolis; and the Liberty Limited between Washington, Baltimore and Chicago.

Altogether, the 114 cars for both roads comprise one of the largest single orders of passenger equipment on record in which low-alloy, high-tensile steel has been used. New York, New Haven & Hartford have some 205 Cor-Ten coaches in operation, but these were built on separate orders.

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Welding Society
ACTIVITIES—Related Events

RESISTANCE WELDER MANUFACTURERS ASSOCIATION

Members of the Resistance Welder Manufacturers Association who will hold a meeting at the Recess Club, Detroit, on Thursday, June 9th, are developing a program of activities designed to improve conditions throughout the industry.

The work is being handled under the direction of Committees appointed by Walter A. Anderson of The Taylor-Winfield Corp., President of the Association. Preliminary reports were considered at a meeting in Detroit early in May, and it is expected that a number of the recommendations now before Members will be finally acted upon at the June meeting.

A committee on Standards, under the Chairmanship of John D. Gordon of The Taylor-Winfield Corp., is giving attention to several problems of general interest to all Members of the Association. Cooperating with Mr. Gordon are Harold B. Warren of the Thomson-Gibb Electric Welding Co., Arthur B. Sonneborn of the Federal Machine & Welder Co. and President Anderson who is serving as an ex-officio Member.

Transformer Specifications

A subject of the utmost concern is the development of standard transformer specifications. This problem is being studied by a Committee acting under the Chairmanship of H. V. Beronius of the Welding Machines Mfg. Co. in cooperation with E. C. Smith of the National Electric Welding Machines Co., M. S. Clark of the Federal Machine & Welder Co. and Walter A. Anderson. This committee will report at the June meeting.

The Association is expected to give publicity to its recommendations from time to time through a Committee that will be headed by Arthur B. Sonneborn of the Federal Machine & Welder Co. as Chairman. Mr. Sonneborn has been authorized to select from the industry other Members of his Committee.

Floyd E. Taylor of the Swift Electric Welder Co. has been appointed Chairman of the Membership Committee.

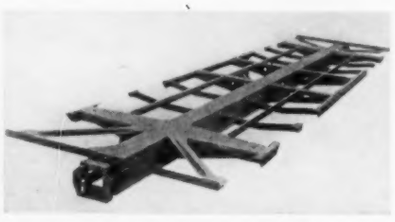
WELDING WIRE BOOKLET

The John A. Roebling's Sons Company, Trenton, New Jersey, has just issued a copy of a new 40-page booklet on Welding Wire.

This booklet illustrates and describes a complete line of both bare and covered electrodes and gas welding wire, giving useful information on the chemical analyses, polarity and use of the various types.

In addition to welding wire, this booklet also contains valuable tables on a Lead or Trailing and Electrode Holder Cables.

FREIGHT CAR UNDERFRAME



Arc-Welded Fabricated Freight-Car Underframe Made by the Ryan Car Co. in South Chicago, Ill.

ALL-WELDED BOAT

The All-Welded, Streamlined "City of Philadelphia" Upon Completion by The Maryland Drydock Company

ARC-WELDING BIG BUILDING

Masked Against a Brilliant Arc Is This Workman Busy on the Construction of One of the Largest All-Welded Buildings in the West. This One-Story Structure Is an Addition to the Emeryville, California, Plant of the Westinghouse Electric & Manufacturing Company, and Is 200 Feet Long by 75 Feet Wide. More Than 350 Tons of Steel Were Required for the Framework

AWARD OF MEDALS

I. Regulations Governing the Board of Awards

1. *Membership.*—The Board of Awards shall consist of three members of the AMERICAN WELDING SOCIETY. One member shall retire each year. The President of the Society shall appoint a member each year to serve from the first day of the month next following the first session of the annual meeting of the Society for a term of three years. The senior member of the Board shall be chairman of the Board of Awards.

2. *Duties.*—The Board of Awards each year shall select the persons to receive the awards made by the Society.

II. Regulations Governing the Award of the Samuel Wylie Miller Memorial Medal

1. *Donor.*—The AMERICAN WELDING SOCIETY.

2. *Purpose.*—To commemorate the many unique contributions of Samuel Wylie Miller to the science and art of welding, his unselfish encouragement of others, his achievements and effective work in convincing engineers and the public that welding should take its rightful place as a recognized method of fabricating metals, and especially his important contributions to the formation and early success of the AMERICAN WELDING SOCIETY.

3. *Award.*—The medal shall be awarded each year to the person who in the judgment of the Board of Awards is most deserving for conspicuous contributions to the advancement of the welding or cutting of metals.

4. *Eligibles.*—Any person shall be eligible for this award whether or not a member of the AMERICAN WELDING SOCIETY.

5. *Presentation.*—The medal for each year together with a suitable certificate shall be presented at a session of the Annual Meeting of the AMERICAN WELDING SOCIETY next following the year for which the award is made. The presentation shall be made by the chairman of the Board of Awards or by a member of the Society designated by the chairman.

III. Regulations Governing the Award of the Lincoln Gold Medal

1. *Donor.*—Mr. J. F. Lincoln, President, Lincoln Electric Co.

2. *Purpose.*—To encourage the presentation before the AMERICAN WELDING SOCIETY of papers which are effective in promoting the use of welding.

3. *Award.*—The medal shall be awarded each year to the author or authors of the paper which in the judgment of the Board of Awards is the greatest

original contribution to the advancement and use of welding.

4. *Eligibles:*

(*a*) For the author or authors to be eligible for this award, the paper shall describe clearly original work done by them or under their supervision on welding in any of its aspects by any method or process.

(*b*) The paper shall be a full disclosure of the subject.

(*c*) The paper shall contain no statement which is unethical advertising or sales promotion. The paper may contain statements of fact including the names of either individuals or organizations of any kind, commercial designations, trade names, etc.

(*d*) Papers having more than three authors shall not be considered for this award.

(*e*) Any one may be an author of a paper considered for this award whether or not a member of the AMERICAN WELDING SOCIETY.

(*f*) For the author or authors to be eligible for this award the paper shall have been published in THE WELDING JOURNAL for the period beginning with the issue next following the Annual Meeting issue for the year next preceding the year for which the award is made and ending with the Annual Meeting issue for the year for which the award is made, and also, the paper shall have been presented or scheduled for presentation either at a meeting of the AMERICAN WELDING SOCIETY or a meeting of any division or section of the Society.

5. *Presentation.*—The medal, bearing on the reverse side the name of each author of the paper, together with a suitable certificate, shall be presented at a session of the Annual Meeting of the AMERICAN WELDING SOCIETY during the year for which the award is made by the Chairman of the Board of Awards or by a member of the Society designated by the Chairman. Each author of the paper for which the award is made shall receive a medal and a certificate and the medals and certificates shall be duplicates.

IV. Regulations Governing the Award of the Industry and Welding Prizes

1. *Donor.*—The Industrial Publishing Company.

2. *Purpose.*—To stimulate interest in the profession of welding engineering in the Land-Grant Colleges including the study of the different welding processes and the art of designing structures for fabrication by welding.

3. *Awards:*

(*a*) *The Industry and Welding Electric Welding Prizes* shall be awarded each year for theses written by students enrolled in a Land-Grant College or University on either the development or use of electric welding or on the design of a product of any kind fabricated by electric welding.

There shall be three cash prizes as follows:

First Electric Welding Prize	$175.00
Second Electric Welding Prize	50.00
Third Electric Welding Prize	25.00

Each prize shall be awarded to the student or students writing the thesis which in the judgment of the Board of Awards is most deserving of that award.

Any one or more of the three prizes shall not be awarded if in the judgment of the Board of Awards no thesis is submitted of sufficient merit to justify the award.

(*b*) *The Industry and Welding Oxyacetylene Welding Prizes* shall be awarded each year for the theses written by students enrolled in a Land-Grant College or University on either the cutting or welding of metals by the use of the oxyacetylene blowpipe or any use of the oxyacetylene blowpipe for the fabrication or heat-treatment of metals.

There shall be three cash prizes as follows:

First Oxyacetylene Welding Prize	$175.00
Second Oxyacetylene Welding Prize	50.00
Third Oxyacetylene Welding Prize	25.00

Each prize shall be awarded to the student or students writing the thesis which in the judgment of the Board of Awards is most deserving of that award.

Any one or more of the three prizes shall not be awarded if in the judgment of the Board of Awards no thesis is submitted of sufficient merit to justify the award.

4. *Eligibles:*

(*a*) For the author or authors to be eligible for these prizes the theses shall have been written while the author or authors were enrolled as students in a Land-Grant College or University. The theses shall have been prepared under the direction and supervision of the college or university and have the written approval of the head of the department in which the student or students were enrolled.

(*b*) Three copies of each thesis and the written approval of the head of the department shall be submitted to the Board of Awards not less than sixty days previous to the first session of the Annual Meeting of the Society in the year for which the prizes are awarded.

(*c*) The theses shall contain no statement which is unethical advertising or sales promotion. The theses may contain statements of fact including the names of either individuals or organizations of any kind, commercial designations, trade names, etc.

(*d*) A thesis having more than three authors shall not be considered for any of these prizes.

5. *Presentation.*—The prizes together with suitable certificates shall be presented at a session of the Annual Meeting of the AMERICAN WELDING SOCIETY during the calendar year for which the awards are made by the chairman of the Board of Awards or by a member of the Society designated by the chairman. Each author of the thesis for which a prize is awarded shall receive in cash the sum given above for the particular prize and a certificate. The certificates shall be duplicates.

STORAGE TANKS

To provide for increased demand for its products, The Atlantic Refining Company will increase the storage capacity of its water terminals at Newark, N. J., New Haven, Conn. and Kettle Point (Providence), R. I. Docking facilities at Newark will also be enlarged.

Two new all-welded steel storage tanks with a capacity of 1,120,000 gallons each will be erected at Newark. One new tank with a capacity of 750,000 gallons will be erected at New Haven, and one new tank with a capacity of 725,000 gallons at Kettle Point. Construction at all three terminals will be started early in June. The contract for the tanks has been awarded to the Chicago Bridge and Iron Company. Total cost of the increased storage and docking facilities will be in the neighborhood of $270,000.

"ARC WELDING AND HOW TO USE IT"

To meet tremendous changes in Arc Welding Equipment, rods and methods, this 340-page book has been brought out by Hobart Brothers. 320 illustrations, and written in the simplest of language, it' most readable and helpful for the beginner as well as the experienced man using welding.

ARC WELDING COURSE

A special course of instruction in Arc Welding Design and Practice under the direction of Mr. E. W. P. Smith, Consulting Engineer, is being sponsored by The Lincoln Electric Company on June 6th to 10th in the Buffalo Catering Co. Auditorium, Buffalo, N. Y. The lecture includes Arc Welding Generators, Different Type of Joints, Welding Various Metals, Design, Inspection, Stresses. Demonstrations will be given at each lecture.

HEATING AND PIPING CONTRACTORS

The program of the 49th Annual Convention of the Heating, Piping and Air Conditioning Contractors National Association held May 31st, June 1st and 2nd at the Hotel Statler, Boston, Mass., includes a report on welding and discussions of welding problems. Report of the Committee on Welding, of which Mr. John H. Zink of Baltimore is Chairman, is published in the Official Bulletin of the Association, June issue, pages 32 to 33.

STEEL CONDITIONING

The Air Reduction Sales Company, 60 East 42nd Street, New York, have just issued an attractive pamphlet on Steel Conditioning with the Oxyacetylene Deseaming Torch. This pamphlet covers Advantages, Technique, Methods, Quality of Work, Layout and other technical information.

WELDED TRAMS FOR TRANSPORTING TELEPHONE POLES

The Joslyn Manufacturing Company, Franklyn Park, Ill., has adopted electric arc welding as a means of fabricating the trams on which it transports telephone and telegraph poles over narrow gage tracks. Previously, these vehicles were constructed by using bolts and rivets but because such fastening devices worked loose after a period of service, necessitating replacement, the company turned to arc welding.

CONSTRUCTION DETAILS OF SPILLWAY GATES AT PICKWICK LANDING DAM

Interesting engineering details are found in the design, fabrication and assembly of the steel spillway gates now being installed in the Pickwick Landing Dam on the Tennessee River. This dam is one of the larger spillway units of the giant T.V.A. project. It contains 22 spillway openings but requires 23 gates in order to provide a spare assembly; all of these were fabricated by Dravo Corporation, Pittsburgh, Pa.

Each gate is composed of separate top and bottom sections, having the vertical side girders equipped with double flange rolled steel wheels mounted on over-hung axles. These wheels, 30 inches in diameter, run on the gate tracks in the gate slots.

The bottom sections will be subjected to the greater pressures and are, therefore, larger and heavier, each weighing about 65 tons. They are 41 feet wide and 20 feet $5^{5}/_{16}$ inches high and have six roller bearing fitted wheels on each side. Heavy fabricated silicon steel girders and diaphragms compose the frame work to which is welded a $^{1}/_{2}$-inch steel skin-plate. It is said that these are the first spillway gates to have welded skin-plates. All other construction is riveted.

The top sections measure 41 feet by 20 feet, but weigh only 40 tons. These parts are equipped with three bronze bushed wheels on each side. Steel work consists of 36 foot—160 pound wide flange rolled beams with supporting diaphragms.

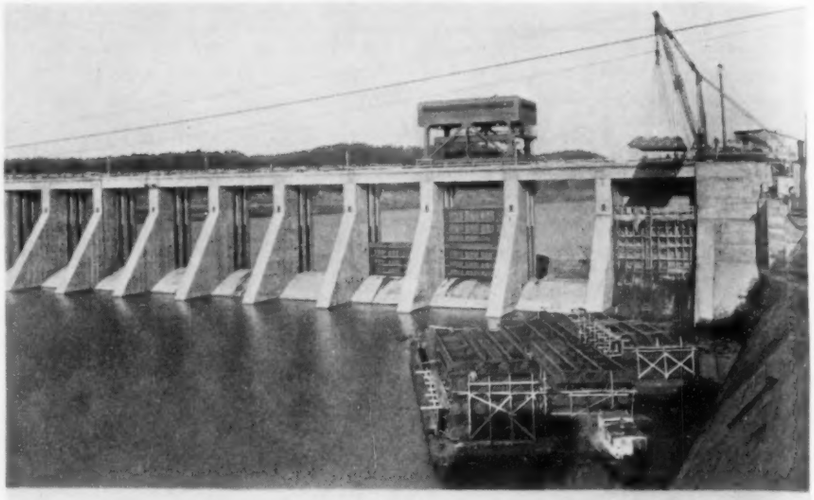
Because of the severe loads imposed upon the wheel assemblies of both sections, both the roller bearing and bushed units were designed to withstand high pressures. Representative roller bearing and wheel assemblies were tested at the Pittsburgh Testing Laboratories for a direct radial load of 160,000 pounds applied at the wheel tread, and a thrust load of 60,000 pounds, acting simultaneously with the radial load. Stationary and $1^{1}/_{2}$ rpm. revolving tests were made.

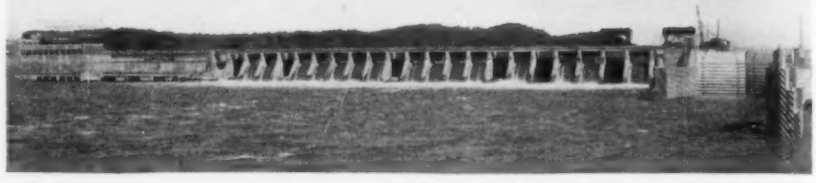
The bronze bushed assemblies received similar tests and were found to be capable of sustaining a direct radial load of 130,000 pounds and a thrust load of 45,000 pounds.

In all, 45 sections have been delivered to the site, by barge, and are now being installed. One upper spillway section is designed to accommodate a special trash gate, specified as part of the contract.

Dravo Corporation is at present engaged in fabricating 38 additional spillway sections of the same type, which will be installed in the Guntersville Dam, another T.V.A. unit on the Tennessee River.

First Gates Being Installed by Traveling Crane on Spillway Deck. All Gates Were Delivered to the Site by Barges as Shown





Completed Dam with Water Flowing Over Spillways. Note Raised Upper Sections of Spillway Gates Allowing Water to Flow

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-268. Acetylene and electric welder desires position. 28 years of age; served apprenticeship with The Lehigh and Hudson River Railway Company, going from there to the New York, New Haven and Hartford Railroad Company. Can furnish references.

A-269. Welding Engineer with welded composite die design and fabrication experience. Excellent references. Can handle men and costs.

A-270. Young man desires position as arc welding operator. Will go anywhere. Would be willing to start as tack welder or welder's helper.

A-271. Young man wishes position as electric or acetylene welder in Central or South America. Eighteen months' experience in all-around shop welding. Completed the Welding Course at the Milwaukee School of Engineering, also have had two years' experience as a Diesel Caterpillar Operator.

A-272. Arc Welder—charge of weld inspection, layout heavy plate from blue print and charge of cutting shop. College graduate and Lincoln trained.

A-273. Nine years' experience as an operator and foreman in electric welding, also some gas experience. Have used all types of coated rod, also, various grades of chrome steel. Have worked on all types of high-pressure vessels, also, pipe, shipyards and tank work for Foster-Wheeler Corp., M. W. Kellogg Co., United Shipyards, Hammond Iron Co., Mitchell-Stewart Construction Co., Westinghouse, Bethlehem Steel, American Bridge and others. Will go anywhere. Field or shop. Will also accept demonstration and sale of wire positions.

A-274. Arc and Gas welder desires position. Have had thorough training. Can weld in all positions.

A-275. Young American, age 36, with successful record of accomplishment on sales force representing one of the world's largest manufacturers of arc welding equipment and electrodes. Fully qualified in all branches. Selling, demonstrating, welding and teaching. References available.

A-276. Welder with fifteen years experience. Passed all Codes, namely, A. S. M. E., Pipe, Navy, Bureau of Steamship and Navigation. Have had experience on structural and boiler work for past three years, have assisted Welding Design Engineers, and have had charge of welding shop.

OBITUARY

George R. Boyce, of A. M. Castle & Co., died at the Passavant Hospital, June fourteenth, after an illness of almost a year as a result of an automobile accident.

Mr. Boyce became associated with A. M. Castle & Co., January 1, 1912, and served as Director and Vice-President in charge of railroad sales for many years.

His loss will be felt keenly by his friends and business associates.

NEW PRODUCTS

The Society assumes no responsibility for the validity of claims in this Section

ELECTRODE FOR STAINLESS STEEL WORK

The Harnischfeger Corporation of Milwaukee, announces Smootharc "Harstain," an electrode designed for welding such brands of chrome-nickel stainless steel as Enduro, KA-2, Allegheny Metal, Uniloy, Duroloy, etc.

"Harstain's" base metal contains 19% chromium, 9% nickel—a higher content of both elements than in the usual 18–8 type of stainless steel. Carbon content of the base wire is below 0.08% to insure high resistance to corrosion. Columbium is added to prevent carbide precipitation, the cause for intergranular corrosion.

WELDING HELMET WITH FLIP-FRONT*

Designed for electric welding in tight places where the conventional style of shield requires too much space. If you can get into working position this helmet will serve to advantage as it will take up very little additional space other than that required by the head.

Manufactured of selected chrome leather on a specially constructed, vulcanized fiber headgear. Headgear is form fitting and adjustable to various head sizes, adjustment being accomplished without the use of tools by means of a screw fitting conveniently located. Extends well down the back and front, giving full protection to the face and ears. Chrome leather is well suited for this type of helmet as it renders good service under extreme heat conditions and the dangerous rays do not penetrate it.

* Industrial Products Company, 770 W. Somerset Street, Philadelphia, Pennsylvania.

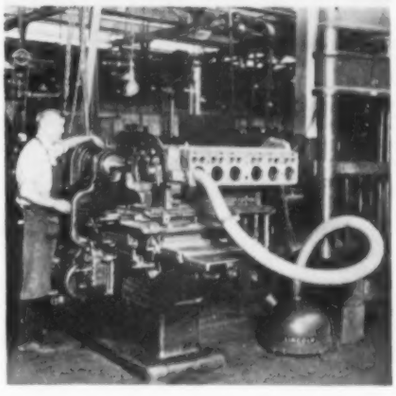
NEW WELDING TIP STANDARDIZATION PROGRAM

Realizing that its welding tip alloys needed a better tip design to yield their full value, P. R. Mallory & Co., Inc. has introduced the New Type pointed welding tip in a complete range of standard sizes. Many different designs were tested by thousands of welds on the most modern spot, gun and other welders, both in the Mallory laboratories and in the big production shops. Punishing overloads were used to prove strength and disclose weakness in design. Welding tip nose forms, water hole depths, wall thickness, etc., were tested thoroughly to determine the best design for maximum efficiency.

AIR CLEANER FOR GRINDING AND WELDING

A new machine, which conditions air by filtering out dirt particles and which is said to remove approximately 95% of the dirt from the air in the vicinity of grinding, welding and other shop operations, is announced by The Lincoln Electric Company, Cleveland, Ohio.

The machine also draws smoke and heat away from the work thus contributing materially to the efficiency of welders and to the general improvement of shop conditions. It can also be adapted for blowing smoke away where such operation is desired.



(Above)—"Linconditioner," New Air Conditioning Machine Being Used in Conjunction with Welding of Copper to Carry Smoke and Dirt Particles Away from the Operator

(Below)—"Linconditioner" Removing Dust Particles from Machining Operation on Engine Cylinder Block

List of New Members

May 1 to May 31, 1938

BOSTON

Trinidad, Antonio C. (D), 22 Swift St., New Bedford, Mass.

CANADA

MacDonald, R. H. (C), Steel Co. of Canada, Ltd., Yonge St., Toronto, Ont., Canada.
Scott, George E. (B), 25 Edith Drive, Toronto 12, Ont., Canada.
Seymour, A. W. (D), 133 Eighth St., Noranda, Quebec, Canada.

CANTON

Vaughen, R. A. (C), 706 W. Niscarawas St., Canton, Ohio.

CHICAGO

Kennedy, Clarence J. (C), American Bridge Co., Gary, Ind.
Smith, Norman E. (D), 11 Ivy St., Joliet, Ill.

CINCINNATI

Harbin, L. N. (C), 3751 Montgomery Road, Norwood, Cincinnati, Ohio.
Luck, W. V. (D), 2737 Alberts Court, Apt. 2, Oakley, Cincinnati, Ohio.

COLUMBUS

Art, Vernon (C), 2286 Indianola Ave., Columbus, Ohio.
Aschinger, Russell R. (B), The Ross-Willoughby Co., Columbus, Ohio.
Moon, Sterling C. (C), 989 Studer Ave., Columbus, Ohio.
Steen, R. H. (C), The Ohio Power Co., Philo, Ohio.

CONNECTICUT

Gray, Joseph G. (C), 133 No. Main St., Ansonia, Conn.
Kelso, George W. (C), 295 East Washington Ave., Bridgeport, Conn.

HAWAII

Lothian, James (B), P. O. Box 206, Ewa, Hawaii.
Wright, Virgil (F), 2174 Tantalus Drive, Honolulu, Terr. of Hawaii.

KANSAS CITY

Dodge, Merle (F), Kansas State College, Shop Practice Dept., Manhattan, Kansas.
Fleming, Allan (D), 3115 Broadway, Kansas City, Mo.
Havens, Harry L. (B), 1713 Crystal Ave., Kansas City, Mo.
Swope, Lynn (B), Hobson-McFarland Tractor Co., 2131 Washington St., Kansas City, Mo.

LOS ANGELES

Eastman, Leslie E. (D), 425 Irving Ave., Glendale, Calif.
Farnsworth, R. D. (D), 3773 Greenwood Ave., Venice, Calif.
Lane, H. A. (D), 1122 W. 107th St., Los Angeles, Calif.
McGinley, Francis V. (D), 810 Terrace 49, Los Angeles, Calif.
Witherspoon, H. C. (C), 4901 Santa Fe Ave., Los Angeles, Calif.

MARYLAND

Shook, Henry W. (C), Standard Oil Co. of N. J., Boston & Dean Sts., Baltimore, Md.

MEMPHIS

Atkins, C. N. (D), Milton Bowers Welding Co., 346 Madison, Memphis, Tenn.
Bowers, Milton (B), 346 Madison Ave., Memphis, Tenn.
Bull, Charles M. (C), 1795 Kendale, Memphis, Tenn.
Campbell, L. W. (C), National Gas Co., 931 Strick Bldg., Memphis, Tenn.
Gifford, R. A. (B), Southern Boiler & Tank Wks., Memphis, Tenn.
Craig, E. S. (C), 307 So. Front St., Memphis, Tenn.
Dedman, S. F. (D), 12–21 Jefferson, Memphis, Tenn.
Drury, B. B., Jr. (C), National Cylinder Gas Co., 238 So. Front St., Memphis, Tenn.
Farrell, O. B. (C), 81 Madison Ave., Room 909, Memphis, Tenn.
Grissom, E. L. (D), 1110 Azalia, Memphis, Tenn.
Hays, D. S. (B), Hays Supply Co., 269 S. Front St., Memphis, Tenn.
Henson, Vergil A. (D), 1630 So. Wellington St., Memphis, Tenn.
Hodgson, Harry (C), Layne-Bowler Co., Chelsea Ave., Memphis, Tenn.
Johnston, C. (D), Milton Bowers Welding Co., 346 Madison Ave., Memphis, Tenn.
Jolly, J. T. (D), 1093 Carr, Memphis, Tenn.
Lea, Warren L. (D), National Cylinder Gas Co., 238 So. Front St., Memphis, Tenn.
Owen, David W. (C), Southern Welding Co., 344 Adams, Memphis, Tenn.
Poundens, J. C. (D), P. O. Box 97, Memphis, Tenn.
Prestwood, Robert L. C. (D), 974 Forrest Ave., Memphis, Tenn.
Sherwood, L. K. (D), Milton Bowers Welding Co., 346 Madison Ave., Memphis, Tenn.
Taylor, W. L. (D), 1126 Forrest Ave., Memphis, Tenn.
Vaughn, J. I. (D), 491 Walker Ave., Memphis, Tenn.
Wood, J. N. (B), 690 N. Willett St., Memphis, Tenn.

MILWAUKEE

Barrett, L. W. (F), 2211 No. 23rd St., Milwaukee, Wis.
Davis, A. E. (F), 1115 No. Jefferson St., Milwaukee, Wis.
Flexer, Russell (F), 1115 No. Jefferson St., Milwaukee, Wis.
Harrington, Stephen (F), % Allen Martin, Livingston, Wis.
Johnston, Gunnar (F), 202 Williams Park, Rockford, Ill.
Smith, Everrett (F), R. F. D. No. 1, Box 4, Cornell, Wis.

MONTANA

Buhrer, Jack L. (D), 3302-A, Fort Peck, Montana.
Simmons, William W. (D), Hinsdale, Mont.

NEW YORK

Chamberlin, John B. (C), Lincoln Elec. Co., 333 W. 42nd St., New York, N. Y.
Connelly, Peter K. (B), 29–23—40th Road, Long Island City, N. Y.
McClintock, Harvey C., Jr. (C), 1435 Lexington Ave., New York, N. Y.
Miron, John (D), Box 15, New Market, N. J.
Schuster, K. R. (B), 125 Cedar St., New York, N. Y.
Stark, Guy F. (C), Industrial Dept., Westinghouse Elec. Inter. Co., 150 Broadway, New York, N. Y.
Thompson, Thomas (D), 240–08 Weller Ave., Rosedale, L. I., N. Y.

NORTHERN NEW YORK

Clark, Le Roy W. (C), Rensselaer Polytechnic Inst., Troy, N. Y.

WESTERN NEW YORK

Bollin, Edward F. (C), 80 Hartwell Road, Buffalo, N. Y.

NORTHWEST

Beilke, Martin (D), 2348 Thomas Ave. N., Minneapolis, Minn.
Gaedy, Clarence (D), Smith Welding Equip. Corp., 2619—4th St. S. E., Minneapolis, Minn.

PHILADELPHIA

Doan, Prof. Gilbert E. (B), Lehigh University, Dept. of Metallurgical Engrg., Bethlehem, Pa.
Miller, Irvin (D), 99 Main St., Mt. Carbon, Pottsville, Pa.
Miller, Robert O. (C), 3rd & Ridge St., Emaus, Pa.

PITTSBURGH

Deacon, A. J. (B), 1438 Grandin Ave., Dormont, Pittsburgh, Pa.
Stuver, E. W. (C), 235 So. Negley Ave., Pittsburgh, Pa.

ROCHESTER

Wise, Grover L. (D), R. D. No. 3, French Road, Penfield, N. Y.

ST. LOUIS

Ryan, Robert J. (C), John Nooter Boiler Wks. Co., 1414 So. 2nd St., St. Louis, Mo.
Schade, Wilbert C., Jr. (C), 7920 Delmar Blvd., University City, Mo.

SOUTH TEXAS

Greer, W. H. (C), 1206½ Preston Ave., Houston, Texas.
Rule, J. O. (D), General Delivery, Texas City, Texas.

TULSA

Wells, C. G. (A), National Tank Co., Box 1588, Tulsa, Okla.

WICHITA

Bates, Harvey C. (C), 337 Main St., Augusta, Kansas.
Croll, Lawrence (D), 425 Clark St., Augusta, Kansas.
Dickerson, R. D. (D), Kansas Gas & Elec. Co., Ripley Station, Wichita, Kansas.
Headrick, B. C. (B), Kansas Gas & Elec. Co., Ripley Station, Wichita, Kansas.
Houser, K. O. (B), Kansas Gas & Elec. Co., Ripley Station, Wichita, Kansas.
Kinder, G. P. (D), Kansas Gas & Elec. Co., 3rd & Kelly Sts., Wichita, Kansas.
Love, R. H. (D), 1130 Fairview, Wichita, Kansas.
McMillan, J. H. (C), Kansas Gas & Elec. Co., Electric Plant, 3rd & Kelly, Wichita, Kansas.
Miller, W. G. (C), Kansas Gas & Elec. Co., Wichita, Kansas.
White, Roy (D), Spencer Trailer Co., Augusta, Kansas.

NOT IN SECTIONS

Applegate, C. W. (F), 1041 So. Downing, Denver, Colo.
Ashton, Frank W. (C), U. S. Engineers, Clock Tower Bldg., Rock Island, Ill.
Ball, Richard (F), 2412 S. Adams St., Denver, Colo.
Brown, Thomas R. (B), The Stearns-Roger Mfg. Co., 1720 California St., Denver, Colo.
Crummy, Ansel J. (F), 1203—1st Ave., Grand Forks, No. Dakota.
Gemmell, Robert D. (B), 2 Rose Court, Main Road, Rondebosch Cape, South Africa.
Gerboth, C. L. (F), 1205 Clermont St., Denver, Colo.
Hearn, W. W. (C), The Iroquois Petroleum Co. Box 309, Haifa, Palestine.
Januks, L. L. (F), 2544 Race St., Denver, Colo.
Keeney, Ray (D), 2139 So. Fox, Denver, Colo.
Leasure, J. B. (F), 2136 Tremont, Denver, Colo.
Nel, Gert Jacobus (B), % Chief Engineer, South African Railways & Harbours, Sta. Bldgs., Pretoria, S. Africa.
Pautler, Arthur (F), 1628 Lincoln St., Denver, Colo.
Perry, Mike F. (F), 1346 Iola St., Aurora, Colo.
Pinczon, J. (C), Chantier de Penhoet, Saint-Nazaire, Loire-Inferieure, France.
Purslow, Herbert (B), Langside, Priory Road, Sale, Nr. Manchester, England.
Reeves, Charles L. (B), Minneapolis-Moline Power Implement Co., Moline, Ill.
Seagler, L. C. (F), Box 312, Wheatridge, Colo.
Stapp, Denton E. (F), 3042 Vine St., Denver, Colo.
Stout, Arthur (B), P. O. Box 239, New Orleans, La.
Walden, Joseph (B), La Gratitude, Lansdowne Rd., Claremont C. P., South Africa.
Woodley, F. C. (F), 120 West 4th Ave., Denver, Colo.

SECTION ACTIVITES

KANSAS CITY

The May meeting of the Kansas City Section was held on Monday the 23rd. The speaker was Mr. Orville Mauck, welding supervisor for the Pipe Line Department of the Sinclair Refining Company. Mr. Mauck's subject was "Maintenance and Construction of Pipe Lines." He had three reels of moving pictures illustrating the subject.

LOS ANGELES

The regular meeting of the AMERICAN WELDING SOCIETY, Los Angeles Section was held Thursday Evening, April 21, 1938 at the Commercial Club, 11th and Broadway, Los Angeles, Calif.

Sixty-five members and guests attended the dinner, with about 110 for the following meeting.

Chairman McElfish called for reports on the Western Regional Conference. Reports were heard from the General Chairman, Wayne Howard; Entertainment Chairman, Harold Etter; Registration Chairman, Merle Turner; and the Secretary.

Wayne Howard has been removed by the General Petroleum Corporation to a new position with the Socony Vaccum Corporation of Brooklyn, N. Y. A rising vote of thanks to Mr. Howard for his work with the AMERICAN WELDING SOCIETY, Los Angeles Section, and appreciation of the membership, were expressed.

Two interesting papers were given. One on "Flame Hardening by the Oxy-acetylene Process" by Mr. W. P. Fisher, Los Angeles Office, Linde Air Products Company, and the other paper by Mr. William Hamilton, Los Angeles Office, Air Reduction Sales Company, on "Low Temperature Brazing." Both papers were supplemented by slides.

Following this, a film on the "Analysis of Welded Joints and Locally Stressed Portions of Vessels by Polarized Light," was presented by Lukenweld Company, Coatesville, Pa.

MILWAUKEE

The last meeting of the 1937–38 season was held on Thursday, June 2, 1938 at the City Club of Milwaukee.

The meeting which was restricted to members and their ladies was devoted to the annual election and a program of entertainment.

The following officers were elected:

Chairman—John G. Shodron, Professor of Industrial Building and Machine Design, Marquette University, Milwaukee, Wisconsin.

Vice-Chairman—John J. Chyle, Welding Research Engineer, A. O. Smith Corporation, Milwaukee, Wisconsin.

Secretary and Treasurer—Gilbert F. Meyer, District Representative, Machinery and Welder Corporation, Milwaukee, Wisconsin.

Director (2 Yrs.)—K. Walker, Welding Engineer, Bucyrus-Erie Co., South Milwaukee, Wisconsin.

Director (2 Yrs.)—J. A. Pawlowski, Welding Engineer, Cutler-Hammer, Inc., Milwaukee, Wisconsin.

Director (2 Yrs.)—F. G. Hibbard, Superintendent of Ways and Structures T.M.E.R. & L. Co., Milwaukee, Wisconsin.

Director (1 Yr.)—R. E. Hawley, Welding Engineer, Oil Gear Co., Milwaukee, Wisconsin.

The meeting afforded an opportunity for the members to become better acquainted and all spent an enjoyable evening.

NEW YORK

A new multi-reel Technicolor sound motion picture on "Steel—Man's Servant" was shown through the Courtesy of U. S. Steel Corporation, at the annual meeting of the New York Section held on Tuesday June 14th. A short talking movie on "Structural Steel Welding Under the New York Building Code" followed. A color film taken and discussed by Arthur N. Kugler, Mechanical Engineer, Applied Engineering Dept., Air Reduction Sales Co., of the first school building built by welding, under the New York Building Code.

The annual business meeting and election of officers was then held in Room 502. The following are the officers and directors elected:

Chairman—J. L. Wilson
First Vice-Chairman—Charles Kandel
2nd Vice-Chairman—J. T. Phillips
Secretary-Treasurer—G. V. Slottman
Directors for 2 years—E. V. David and E. Vom Steeg, Jr.
For 3 years—R. W. Boggs, G. N. Bull, A. F. Keogh, S. S. Scott.

NORTHWEST

At the first meeting of the newly elected Executive Committee held May 26th, John Nelson, Vice-President and Manager, Butler Manufacturing Company, Minneapolis, the newly elected Chairman, announced the appointment of the following committees to serve during the current year:

PROGRAM

R. H. Newton, Chairman, Lincoln Electric Co., T. P. Hughes, University of Minnesota, G. W. Irwin, Air Reduction Sales Co.

MEMBERSHIP—MINNEAPOLIS

Fred Klass, Chairman, General Electric Co., C. M. Akins, Marquette Mfg. Co., E. A. Cook, Harnischfeger Corporation, Amos Johnson, Commercial Gas Company, J. E. Williams, The Linde Air Products Co.

MEMBERSHIP—ST. PAUL

H. A. Lindeke, Chairman, Nicols, Dean & Gregg, J. H. Barron, Brown Sheet Iron & Steel Co., C. E. Comfort, St. Paul Structural Steel Co., Wm. H. Grohs, Page Steel & Wire Co., Emil C. Schroeder, Paper Calmenson & Co., Wm. H. Schulz, Donaldson Co. Inc.

MEETINGS

R. W. Robinson, Chairman, American Bridge Co., E. R. Johnson, Westinghouse Electric & Mfg. Co., Thos. J. Warmington, Wm. Bros. Boiler & Mfg. Co., G. V. Watson, Flour City Welding Co.

Both the Minneapolis and St. Paul Membership Committees have met and organized their plan of procedure. Already there are evidences of keen rivalry between the two committees. This has been accentuated by the offer of Chairman Nelson to buy a dinner for the committee which first brings in before next Thanksgiving fifteen new members in Classes B or C.

The Program Committee under Chairman Newton is actively engaged in arranging a program of meetings for the year. A number of nationally recognized experts will be invited to present papers at the Section's meetings this fall and winter.

OKLAHOMA CITY

A very interesting and well attended meeting held June 7th closed the public activities of the Oklahoma City Section for the 1937–38 season.

This meeting being what might be termed the first annual meeting consisted of a program devoted to business and to education.

The educational part of the program was furnished by Louis R. Hodell of Tulsa, Research Engineer for the Carter Oil Company who spoke on the subject "The Welding of Oil Well Casing." The talk was illustrated by slides and motion pictures.

The business portion of the meeting consisted of reports of the various Committee Chairmen covering their work during the past year. All of these reports gave evidence of the work done by the various committees—this work resulting in the interesting programs held throughout the year, a rather steady increase in membership together with a satisfactory report as to the financial status of the Section.

Mr. Barnett, the Section's Chairman, gave a brief report summarizing the work of the section at the conclusion of which he was presented with an AMERICAN WELDING SOCIETY pin in appreciation of his work during the past year.

The following officers were re-elected: O. T. Barnett, Chairman, K. B. Banks, Secretary, and Otto Hart, Treasurer.

Francis Sprehe was elected as Vice-Chairman and Joseph Mideke, Clovis Gee, Geo. E. Day and C. C. Willis were elected as members of the Executive Committee.

Before adjourning the meeting, Mr Barnett announced appointment of the Committee Chairmen for the coming season appointing C. C. Willis as chairman of the Program Committee, M. F Dunne, Chairman of the Membership Committee and Charles Bowen as Chairman of the Educational Committee.

PHILADELPHIA

The Philadelphia Section announces the election of a new Chairman of the Membership Committee—J. J. Dunne, Paschall Oxygen Co., 73rd & Woodland Avenue.

SAN FRANCISCO

The regular monthly meeting of the San Francisco Section was held at the Athens Athletic Club, Oakland, May 27th. Lieut. Commdr. McCord spoke on the subject of X-ray to determine defects in welds, castings, etc. He then showed a series of slides depicting various castings and welds which had been X-rayed, pointing out the apparent defects as disclosed by the X-ray. Following the showing of these slides there was an interesting question and answer period.

Following this the Tellers reported the results of the election which were as follows:

Chairman—Professor N. F. Ward
Vice-Chairman—T. R. Rooney
Secretary—J. G. Bollinger
Treasurer—H. W. Saunders
Executive Committee—K. V. King, C. S. Smith, E. L. Mathy.

Mr. H. W. Saunders reported that as a member of the Special Events Committee for the World's Fair to be held on Treasure Island in 1939, that Sunday, September 24, 1939 had been designated as Welders' Day at the Fair.

SAN JOAQUIN VALLEY

Regular meeting of this Section was held on May 19th in Druids Hall, Bakersfield, Calif. Mr. J. W. Steen, Standard Oil Co. was elected Chairman and Mr. Guy D. Atmore, Air Reduction Sales Co., was elected Vice-Chairman for the year 1938–39. Mr. Killian gave a highly educational and interesting lecture on the subject "Stainless Steel."

A motion picture "Wheels Across Africa" was extremely interesting as well as educational and thoroughly enjoyed by every one.

Refreshments were served following the program. Forty-eight members and guests were present.

ST. LOUIS

The newly elected officers of the St. Louis Section for the fiscal year June 1, 1938 to June 1, 1939 are as follows:

Chairman—F. C. Fantz
Vice-Chairman—N. F. Moss
Treasurer—A. S. Schwarz
Directors—A. Allina, A. W. Harris, J. G. Rosborough, Jr., A. R. Ross, W. M. Schenler, R. C. Thumser.

This group composes the Executive Committee. The Secretary for the ensuing year will be elected by this Executive Committee at its regular monthly meeting in July.

The Annual Meeting of the Section was held Friday, June 10th at the York Hotel. Two hundred and thirty-six were in attendance. At this meeting the annual reports of the Officers were made and the new Officers installed. A. W. Harris, the outgoing Chairman and F. C. Fantz, the incoming Chairman were presented with gavels, appropriately inscribed as momentoes of their term of office. It is intended that hereafter annually the incoming Chairman will be presented with a similar gavel.

No meetings of the Section will be held during July and August. R. C. Thumser, Chairman of the Program Committee, has practically completed the programs for the monthly meetings from September 1938 to May 1939 inclusive. As soon as available these programs will be printed.

SOUTH TEXAS

The June meeting of the South Texas Section was held on Friday, the 17th, in the Chamber of Commerce Assembly Room, Houston. An illustrated lecture on "Machine Gas Cutting Application in Industry" was given by Mr. R. F. Helmkamp from the Magnolia Airco Gas Products Company.

MEMPHIS—PROPOSED SECTION

At a special meeting of interested parties, at the Chisca Hotel, March 3rd, formation of the Memphis Section was completed. Mr. F. V. Winzell of the General Electric Company, St. Louis, Mo., gave a short talk on the purposes of the AMERICAN WELDING SOCIETY, the work it has accomplished and some of the benefits to be derived from membership.

Mr. F. C. Fantz, Vice-President and Chief Engineer of the Midwest Piping & Supply Co., St. Louis, Mo., gave a very interesting talk on the application of welding in their plant, mentioning some of the major problems they encountered, and illustrated with lantern slides, how these problems were overcome. The following officers were elected:

Chairman—Milton Bowers, Pres., Milton Bowers Welding Co.
Vice-Chairman—D. S. Hays, Hays Supply Co.
Secretary—John N. Wood, Firestone Tire & Rubber Co., Memphis.

Annual Dinner Meeting, St. Louis Section, A.W.S., York Hotel, June 10, 1938

TENTATIVE PROGRAM

19th
ANNUAL MEETING
AMERICAN WELDING SOCIETY
DETROIT, MICH., OCTOBER 16 TO 21, 1938

BOOK-CADILLAC HOTEL

PRESIDENT'S RECEPTION SUNDAY, OCTOBER 16th, Afternoon—5 to 7 P.M.

MONDAY, OCTOBER 17th, Morning—9:30 A.M.

Address, by **RICHARD W. READING**
Mayor of City of Detroit

PRESENTATION OF MEDALS

TECHNICAL SESSION

Chairman, P. G. Lang, Jr.
The Baltimore and Ohio Railroad

Vice-Chairman, C. A. McCune
Magnaflux Corporation

WELDING IN CONSTRUCTION WORK

The Oxyacetylene Welding of Carbon Molybdenum Steel Pipe, by A. N. KUGLER,
Applied Engineering Dept., Air Reduction Sales Company

Single Pass Electric Welding of Unfired Pressure Vessels,
by R. M. WALLACE, Asst. Supt., The Griscom Russell Company

Welding Structures, by ALBERT S. LOW, Vice-President, The Austin Company

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SIMULTANEOUS TECHNICAL SESSIONS

PRODUCTION WELDING SMALL MACHINE PARTS

Chairman, K. L. Hansen
Harnischfeger Corporation

Vice-Chairman, F. E. Rogers
Air Reduction Sales Company

Welding, Cutting and Machine Design of Small Sub-Assemblies
by EDWARD J. DE WITT, Vice-President
Wallace Supplies Mfg. Company

Welding as Applied to Fabrication of Industrial Stokers
by F. R. MASON, Riley Stoker Corp.

Methods for the Manufacture of Precision Assemblies by Resistance Welding
by F. D. ROGERS,
International Business Machines Corp.

Arc Welding as Influenced by Shop Preparation, Tools, Jigs and Fixtures
by M. S. EVANS,
American Car & Foundry Company

INDUSTRIAL RESEARCH SESSION

Chairman, Col. G. F. Jenks
Ord. Dept., U. S. Army

Vice-Chairman, E. Vom Steeg, Jr.
General Electric Company

Physical and Chemical Properties of the Nickel-Iron Alloys Formed in the Welding of Nickel Clad Steel
by W. G. THEISINGER, Lukens Steel Co.
J. H. DEPPELER, Metal & Thermit Corp., and
F. G. FLOCKE, International Nickel Co.

Weldability of Medium Carbon Steels
by R. W. EMERSON, Westinghouse Elec. & Mfg. Co.

The Effect of Current, Pressure and Time on the Shear Strength and Structure of Spot Welds in the Aluminum Alloys,
by G. O. HOGLUND and G. S. BERNARD, JR
Aluminum Company of America

An Investigation of Arc and Gas Welded Joints in Aluminum and Aluminum Alloys
by Lieutenant Commander R. K. WELLS (CC) U. S. N.
and A. G. BISSELL,
Bureau of Construction and Repair, Navy Dept.

TUESDAY, OCTOBER 18th, Morning—9:30 A.M.

SIMULTANEOUS TECHNICAL SESSIONS

WELDING AND CUTTING PROCESSES

Chairman, E. A. Balsley
Link Belt Company
Vice-Chairman, P. J. Horgan
General Electric Company

Flame Cutting
by J. J. CROWE, Air Reduction Sales Company

Bi-Metal Construction of High Temperature Steel Valves
by E. R. SEABLOOM, Crane Company

Weld Penetration
by JOHN HRUSKA,
Chief Metallurgist, Electro-Motive Corp.

Bronze-Welding
by W. S. WALKER
The Linde Air Products Company

FUNDAMENTAL RESEARCH SESSION

Chairman, A. B. Kinzel
Union Carbide and Carbon Research Laboratories, Inc.
Vice-Chairman, Milton Male
U. S. Steel Corporation of Delaware

A Quick Shop Test for Quality of Weld and Its Correlation with the Standard Tests
by W. J. CONLEY, The University of Rochester

Effect of Rigid Beam-Column Connections on Column Stresses
by INGE LYSE and E. H. MOUNT, Lehigh University

Residual Stresses Due to Circumferential Welds in Pipes
by E. L. ERIKSEN, University of Michigan

Some Electrical Characteristics of Arc
by Dr. C. G. SUITS, Research Laboratory,
General Electric Company

Afternoon—2:00 P.M.

SIMULTANEOUS TECHNICAL SESSIONS

JOINT SESSION WITH AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Vice-Chairman, C. W. Obert
Union Carbide and Carbon Res. Labs.

Welding by Ammonia Containers
by E. H. BEHLING, Vilter Mfg. Co.

Brazing Tubes in High-Pressure Boilers with Silver Alloys
by A. W. WEIR, New York Central Railroad and H. M. WEBBER, General Electric Co.

Welding Bronze and Non-Ferrous Alloy Piping
by H. D. LANTERMAN
Carbide and Carbon Chemicals Corp.

Effect of Different Preheating and Annealing Temperatures on Welded Carbon Molybdenum Piping
by R. W. CLARK, General Electric Company

FUNDAMENTAL RESEARCH SESSION

Chairman, J. J. Crowe
Air Reduction Sales Company
Vice-Chairman, E. R. Benedict
Contract Welders, Inc.

Weld Quench Test for Weldability of Steels
by W. H. BRUCKNER, University of Illinois

Metallurgical Aspects of Resistance Welding Electrodes
by DR. R. H. HARRINGTON
Research Laboratory, General Electric Company

Creep Test of Arc-Welded Low-Carbon Steel
by N. F. WARD, University of California

Stress Distribution in Welds Subjected to Bending
by C. D. Jensen, Lehigh University

Evening—**Fundamental Research Conference**

WEDNESDAY, OCTOBER 19th, Morning—9:30 A.M.

SIMULTANEOUS TECHNICAL SESSIONS

WELDING IN MACHINE DESIGN

Chairman, Everett Chapman
Lukenweld, Inc.
Vice-Chairman, W. W. Petry
The Cincinnati Milling Machine Company

Recent Developments in Welding of Machine Tool Structures
by L. F. NENNINGER, Chief Engineer, and W. A. MADDOX, Welding Supervisor
The Cincinnati Milling Machine Company

Machine Flame Cutting with Small Machines
by OTTO C. VOSS, Allis-Chalmers Mfg. Co.

Welding and Cutting in Machinery Construction
by J. GORDON, General Manager
Taylor Winfield Corp.

INDUSTRIAL RESEARCH SESSION—

Symposium on Copper Alloy Welding

Chairman, C. H. Jennings
Westinghouse Elec. and Mfg. Co.
Vice-Chairman, W. M. Hayes
Air Reduction Sales Co.

Progress in Copper Welding
by IRA T. HOOK, Research Engineer, and CLINTON E. SWIFT, Welding Engineer
American Brass Company

Testing of Spot Welds on Copper-Base Alloys
by D. K. CRAMPTON, M. L. WOOD and J. C. BABIN, Chase Brass and Copper Co.

Carbon Arc Welding of Silicon Bronze
by E. S. BUNN and J. R. HUNTER
Revere Copper and Brass, Inc.

Afternoon—**Exhibits**
No Technical Sessions Scheduled

THURSDAY, OCTOBER 20th, Morning—9:30 A.M.

AUTOMOTIVE SESSION

Chairman, Walter Anderson
Taylor Winfield Corporation

Vice-Chairman, C. L. Eksergian
Budd Wheel Company

Flame Hardening with the Oxy-Acetylene Flame
by H. J. SHEPPERD, Chief Metallurgist
Kelsey Hayes Wheel Co.

Automobile Body Welding
by E. H. FOSS, The Murray Corporation of America

Welding of Rear Axle Housings
by E. L. BAILEY and V. KNECHT,
Chrysler Corporation

Afternoon—2:00 P.M.

AUTOMOTIVE SESSION

Chairman, Vaughan Reid
City Pattern Works

Vice-Chairman, A. S. Douglass
The Detroit Edison Company

Resistance Welding in the Automotive Industry
by A. DI GIULIO, Ford Motor Company

Use of Welding in Reconditioning Used Cars
by T. W. MOSS, Chrysler Motors Service

Automatic Carbon Arc Welding in the Automotive Industry
by F. M. MAICHLE, The Lincoln Electric Company

Welding Road Equipment
by ELMER ISGREN, Supt.
R. G. Le Tourneau, Inc.

Evening—**Dinner**—7:00 P.M.

HARVEY CAMPBELL, Toastmaster, Detroit Board of Commerce

Principal Speaker, **W. J. CAMERON,** Ford Motor Company

FRIDAY, OCTOBER 21st, Morning—9:30 A.M.
SIMULTANEOUS TECHNICAL SESSIONS

SHIP SESSION

Chairman, A. G. Bissell
Bureau of Construction & Repair, Navy Department
Vice-Chairman, S. S. Scott
Brooklyn Navy Yard

All-Welded Steel Power Boats
by MILO BAILEY, Bailey Steel Shipbuilding Co.

Erection Sequence and Welding Procedure of All-Welded Lake Freighters
by RUSSELL BRENDLE
Great Lakes Engineering Works

Welding Coast Guard Vessels
by D. E. WHITEHOUSE
Defoe Boat and Motor Works

RAILROAD SESSION

Chairman, H. C. Boardman
Chicago Bridge & Iron Company
Vice-Chairman, A. G. Oehler
Railway Age

Welding in Car Construction
by A. M. UNGER, Pullman-Standard Car Mfg. Co.

Flash Welding of Rails
by H. C. DRAKE, Sperry Products, Inc.

Machine Gas Cutting in a Large Steel Foundry
by W. D. MURRAY, General Foreman
Steel Foundry Division, Canadian Car & Foundry Ltd. and
H. E. HORWOOD
Railway & Eng'g Specialties Ltd.

11:30 A.M.—**BUSINESS MEETING**—Election of Officers; President's Report; Board Luncheon

Afternoon—**Exhibits and Inspection Trips**

Optional trips will be arranged to any of the following companies:
Ford Motor Company; Cadillac Motor Company; Chrysler Corporation

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THE ENGINEERING FOUNDATION
Welding Research Committee
Sponsored by the American Welding Society
and American Institute of Electrical Engineers

Supplement to the Journal of the American Welding Society, July 1938

WELDING CHROMIUM STEELS (up to 10% CR)

A Review of the Literature to July 1, 1937

By W. SPRARAGEN* and G. E. CLAUSSEN†

This report is prepared under the auspices of
THE LITERATURE DIVISION OF THE ENGINEERING FOUNDATION
WELDING RESEARCH COMMITTEE

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Summary

WELDING LOWER CHROMIUM STEELS

Mechanical Properties

There are not sufficient data available to draw general conclusions. While excellent strength may be obtained in arc, gas and flash welds, ductility and impact values are dependent, first, on the carbon content, which should preferably be below 0.15%, and, secondly, on the other alloys present. Annealing at 900° C., of course, improves ductility.

Surfacing

The cracking difficulty in welded chromium steels increases as carbon and chromium contents increase. Steels containing chromium alone have been recommended on several occasions for surfacing worn rails. One of several high-carbon, low-chromium steels recommended for surfacing rails by the oxyacetylene process contains 0.84 C, 0.40 Mn, 0.017 Si, 0.42 Cr.

Recovery

In arc welding using a bare electrode containing 1.18 Cr less than 75% was deposited in the weld. The recovery may be as low as 20% with a rod containing

* Secretary, Welding Research Committee.
† Research Assistant, Welding Research Committee.

3.37 C, 9.20 Mn, 32.35 Cr. With a covered electrode of 4–6% Cr about 75% was deposited (percentages as high as 90% have been reported). In oxyacetylene welds 0.3–0.4 Cr may be introduced by coating the filler rod with ferrochromium.

Flame Cutting

With up to 3.5 Cr there is no difficulty in burning, that is, oxidizing the metal during flame cutting, and the slag flows freely. The steels with high carbon and chromium (up to 10% Cr) are air hardening and must be heat treated to soften the kerf.

As would be expected, chromium steels yield high hardnesses in flame hardening.

WELDING 4–6% CHROMIUM STEELS

The low-carbon steels with 4 to 6 Cr and usually $^1/_2$% Mo are widely used as welded oil still piping. The hardness of weld-metal in an arc weld in 4–6 Cr, $^1/_2$ Mo steel (150 Brinell) made with electrodes of the same analysis may be 340–430 Brinell. Preheating locally or entirely to 150–200° C. (300–400° F.) is necessary to prevent air hardening and cracking during welding. Immediately after welding and without allowing the part to cool below preheating temperature, the welded part must be annealed. Annealing for 4 hr. at 700° C. (1300° F.) followed by air cooling reduces the hardness of the weld to 200 Brinell. The carbon should preferably be below 0.12%. Titanium, columbium or aluminum may be added to the base metal and, in some circumstances, to the welding rod to decrease excessive air hardening.

In oxyacetylene welding $^1/_4$-inch plate containing 0.07 C, 5.51 Cr, 0.56 Mo good physical properties were obtained with blowpipe annealing (1 or 2 minutes at 800–900° C.). The structure of an annealed weld is better than base metal and tensile specimens (no reduced section) usually fail in the weld with considerable necking. Arc welds in 4–6 Cr steel pipe with $^3/_4$-inch wall may be bent 180° around $^3/_4$-inch pins without cracks after heat treatment.

WELDING OTHER MEDIUM CHROMIUM STEELS

Steels containing 0.15 C max, 0.30–0.60 Mn, 0.50 Si max., and either 1.75–2.25 Cr, 0.40–0.60 Mo, or 2.75–3.25 Cr, 0.80–1.00 Mo (Croloy steels) are air hardening and must be preheated to at least 150° C. (300° F.). Since the heat-affected zone in the as-welded condition is 275–375 Brinell, the welds should be either annealed at 830° C. (1525° F.) and cooled in the furnace not faster than 33° C. (60° F.) per hr., or stress annealed a short time at 720–750° C. (1325–1375° F.) and air cooled. The electrode should deposit metal of the same analysis as base metal. Oxyacetylene and atomic hydrogen processes are entirely satisfactory.

WELDING CHROMIUM-VANADIUM STEELS

Mechanical Properties

Butt welds (arc and gas) in 16 and 18 gage sheet (S. A. E. 6130) made with a rod containing 0.06 C, 0.15 Mn, 0.08 Si, had a tensile efficiency of over 100% with bead on or off. The welds could be bent 180° in most cases, but if the bead was on the tension side, the bend angle was reduced to 50° in some specimens. Weld-metal containing 0.25–0.30 C, 0.5–0.7 Mn, 0.2–0.3 Si, 1.0 Cr, 0.15–0.20 V has a yield strength of 65,000–90,000 lb./in.^{2}; tensile strength 90,000–105,000 lb./in.^{2}; elongation 17–22% in 2 inches; reduction of area 45–50%. Good atomic hydrogen and resistance flash welds have been made in medium carbon chromium-vanadium steels, for example, 0.17–0.22 C, 0.60–0.75 Mn, 0.15 Si, 0.65–0.80 Cr, 0.12–0.16 V.

WELDING CHROMIUM-MOLYBDENUM STEELS

The chromium-molybdenum steels have been used to a great extent in aircraft construction where their air-hardening capacity combined with high strength and good ductility have been most valuable. Their freedom from temper brittleness has also been an advantage in heat-treated assemblies.

Mechanical Properties

Oxyacetylene butt-welded Cr-Mo sheet and tubing in as-welded or normalized condition has about the same strength as rolled or normalized base metal, provided the weld is free from cracks and base metal is not too thin. Arc and gas welds have been produced in chromium-molybdenum steels 0.04 to 0.12 inch thick, 0.26 C, 0.3 Si, 0.6 Mn, 1.0 Cr, 0.2 Mo, 0.01 S, 0.015 P having tensile strength of 92,000 lb per sq in. as-welded, 130,000 to 135,000 after oil quenching from 850° C. and drawing $^1/_2$ hr. at 600° C. In the latter condition failure in many cases was in base metal next to, or at a considerable distance from the weld.

Unmachined oxyacetylene butt welds in Cr-Mo sheet 0.063 to 0.188 inch thick made with a Cr-Mo steel rod have the same strength as unwelded tubing in the same condition of heat treatment (normalized or oil quenched from 870° C. and drawn at 260 to 600° C.). In sheet 0.031 inch thick the joints may be 15% weaker than unwelded base metal. With a plain carbon steel rod using neutral flame or carburizing flux technique the welded sheets are 20 to 30% weaker than base metal after being oil-quenched from 870° C. and drawn at 260° C., but there is little difference between the low-carbon steel weld and Cr-Mo base metal if the drawing temperature is 600° C. In tubing, the effect of drawing temperature in decreasing the difference between welded joint and base metal (unalloyed weld-metal) is more marked than in sheet. Static tensile failure of unmachined unheat-treated oxyacetylene butt welded S. A. E. 4130 occurs in the softened zone of base metal some distance from the weld unless there is misalignment. The ductility of welded tubular joints varies between 60 and 71% of unwelded.

The reversed bend fatigue strength of oxyacetylene and atomic hydrogen welded seamless tubing is favorably affected by heat treatment. Endurance (reversed bend) limits of 18,500 to 24,200 lb./in.^{2} in the as-welded condition were raised to 22,500 to 29,300 lb./in.^{2} by heat treatment. Unwelded tubing had an endurance limit of 41,800 lb./in.^{2} With tensile stress pulsating from zero to a maximum the endurance limit was 19,200 lb./in.^{2} for the as-welded tube, 21,400 lb./in.^{2} for the heat-treated. The corresponding values for alternating axial stress (± S max.) are ±9300 and ±10,700 lb./in.^{2}, respectively.

Hardness

Reenforced butt welds in aircraft tubing usually failed outside the weld, unless there were major defects in the weld or the joint had been heat treated. The soft zone in S. A. E. X4130 tubing 1 inch o.d., 0.065-inch wall was $^3/_4$ inch from the oxyacetylene weld, $^3/_8$ inch from the arc weld, and about $^3/_{16}$ inch from the flash weld. Air cooling from 885° C. (1625° F.) accentuated the soft zone of the oxyacetylene welded joint, but another investigator found that with thick sheet ($^1/_8$ in.), normalizing eradicated the soft zone of oxyacetylene welded joints. Perhaps flame conditions were different in the two sets of tests. Measured from the center line of the weld, the width of the heat-affected zone was:

Wall thickness, inch:	0.031	0.063	0.125	0.188
Width of heat-affected zone, inch:	$^6/_{32}$	$^7/_{32}$	$^{18}/_{32}$	$^{24}/_{32}$

Metallography

Although chromium and molybdenum lower the critical cooling velocity of steel if they are in solid solution, the heat-affected zone during welding reaches a high temperature for so short a time that the grain size remains fine. The structure of the soft zone depends on the structure of the tube prior to welding. The ability to develop high properties in the heat-treated condition depends on the cleanliness, grain size and composition of the weld-metal. Non-metallic inclusions, such as sulphides, may have a bad effect on welded Cr-Mo steel, but their rôle is still disputed.

Cracking

Welds in Cr-Mo aircraft steels sometimes crack during welding. The cracks generally appear in base metal very close to the weld (0.01 inch or so away). It has been found that the crack sensitivity increased with the carbon, sulphur, and phosphorous content of the steel. Special refining treatment of both open-hearth and electric furnace steels may reduce the crack sensitivity.

Results show that if the steel contains up to 0.02 S and up to 0.025 P at 0.23 to 0.27 C, 0.5 to 0.7 Mn max., 0.3 Si, 0.9 to 1.1 Cr and 0.15 to 0.25 Mo, there should be no difficulty with cracking during oxyacetylene welding. With atomic hydrogen welding sulphur up to 0.043% is not a factor.

Cr-Mo aircraft steels are less sensitive to cracking in the rigid assembly cracking test with atomic hydrogen welding than with oxyacetylene. Metal arc welding was even better than atomic hydrogen welding from the standpoint of cracking. The differences in cracking among the three welding processes in rigid assembly tests is attributed to the differences in heat input, arc welding producing the narrowest heat-affected zone and the least cracking due to reaction stresses. Doubtless, other factors are at work, too.

The following facts appear to have been established:

1. The cracks are intergranular and occur at elevated temperatures, somewhere between 500 and 1100° C.
2. Unusually high sulphur and phosphorous content has an adverse effect.
3. The welding process affects crack sensitivity, (the carburizing flux technique has been successful in avoiding cracks in thin-walled tubing—$1^1/_2$ inches o.d., 0.020-inch wall—where many other remedies failed).
4. Preheating reduces cracking.
5. Special melting and deoxidizing procedures in the manufacture of the steel reduce cracking.
6. Thin sheets crack more readily than thick. Many other factors: grain size of ingot, McQuaid-Ehn grain size, martensite, oxygen, hydrogen, nitrogen, size of ingot, segregation, type of scrap, casting temperature and carbon content, have been found to affect cracks, but equally careful investigators are not in agreement on any of them.

Welding Procedure

Oxyacetylene Welding.—Low-carbon steel rod (0.06 C, 0.15 Mn, 0.06 Si) without flux is satisfactory for S. A. E. X4130. S. A. E. X4140 is not recommended for welding, but, if used, it should always be heat treated after welding. The most prolific source of weld failures is the neglect to melt the base metal (cold welds). In a joint between members of unequal section, the thicker section should be preheated. Excessive difference in thickness may result in burning the thin steel. The repeated application of heat on the small area in a cluster where all the members meet weakens the base metal. Not more than six members should converge at a cluster. Welding should be toward rather than away from edges in order to avoid edge cracking.

Arc Welding.—In the arc welding of S. A. E. X4130, preheating to 150 to 260° C. (300 to 500° F.) avoids a brittle heat-affected zone. Shielded arc, carbon-molybdenum electrode arc recommended with procedure the same as for unalloyed steel. Stress annealing at 600 to 650° C. (1100 to 1200° F.) is desirable.

Resistance Welding.—Spot and flash welds have been produced in chromium-molybdenum tubing (0.25 C) having excellent physical properties.

In spot welds the results show that cooling the weld under electrode pressure is beneficial but reheating is hardly justified.

Flash welds had an endurance (rotating bend) limit of 24,000 lb./in.^{2} as-welded and 32,000 lb./in.^{2} in the heat-treated condition (unwelded tube 41,000 lb./in.^{2}).

WELDING OTHER CHROMIUM-MOLYBDENUM STEELS

Oxyacetylene butt welds in superheater tubes (0.15 C, 0.76 Mn, 0.31 Si, 0.71 Cr, 0.41 Mo) that were normalized, then held 2 hr. at 700° C. before welding were made with a welding rod of the same analysis. A creep test at 500° C. for 50 hr. at a stress of 21,400 lb./in.^{2} (about 90% of the creep strength of unwelded base metal) showed that none of the welds exceeded a creep rate of 10×10^{-4}% per hour. There were no oxide inclusions in flash welds in Cr-Mo tubes made under a protecting gas which prevented scaling of the steel during welding, and the mechanical properties were better than those of welds made in air.

WELDING NICKEL-CHROMIUM STEELS

Mechanical Properties

Good oxyacetylene welds have been produced with nickel-chromium steel rods containing 0.11 C, 0.48 Mn, 0.30 Si, 0.008 P, 0.019 S, 3.58 Ni, 0.71 Cr. Strengths in excess of 100,000 lb./in.^{2} and 39% elongation have been secured in plain carbon steels.

Flame Cutting

It has been found that the heat-affected zone in oxyacetylene flame cut armor plate containing 0.35 C, 3.2 Ni, 1.7 Cr was 0.28 and 0.16 inch deep in steels 16 and 1.58 inches deep, respectively.

Welding Chromium Steels (up to 10% Cr)

INTRODUCTION

THE lower-carbon, low- and medium-chromium steels do not tax the manipulative skill of the welder. Nevertheless, if desirable combinations of mechanical properties are to be secured in the welded joint, it has been the general experience that preheating, heat treatment, or special alloying elements may have to be adopted, especially in the medium-chromium steels. The welding practices that have been employed, as well as the properties and structural peculiarities of the welds in chromium steels containing less than 10% Cr are summarized in this review of literature. Several of the chromium steels containing other alloying elements, notably vanadium and molybdenum, have received a great deal of attention from the welding standpoint. As much, if not more, is known about the welding of chromium-molybdenum aircraft steel, for example, as about any other alloy steel excepting stainless steel. In some instances, the addition of alloying element (except vanadium and molybdenum, for instance) is so small, e.g., 0.1%, that the composition may almost be considered a plain chromium steel. To avoid confusion, however, each class of chromium alloy steel (steels in which the content of chromium predominates) has been dealt with separately in individual sections. Chromium steels containing over 10% Cr or containing alloying elements other than, or in addition to, Ni, V and Mo will be made the subject of future reviews. Subjects that have been discussed in earlier reviews, e.g., fatigue strength, shrinkage stresses and castings, are not discussed again in the present review unless more information has accumulated.

CHROMIUM IN STEEL

The effects of up to 10% chromium in steel have been described fully by Kinzel and Crafts in their Alloys of Iron Research Monograph entitled Alloys of Iron and Chromium, Vol. I, Alloys Containing up to 10% Cr (1937) and by R. H. Greaves in Chromium Steels, London (1935).

In steel refining chromium is easily lost by oxidation. The oxides of chromium that may be formed in the steel bath have a high melting point (chromite $FeO \cdot 3\ Cr_2O_3$ melts at 2180° C.) and are not easily removed. Chromium is soluble in iron in all proportions at all temperatures with the exception of a low-temperature phase that may occur at about 50% Cr. In steels containing more than about 4% Cr, the carbon is in the form of chromium carbide, Cr_7C_3, or mixtures of iron and chromium carbides at room temperature. Chromium favors deep hardening, but is not so powerful in lowering the rate of transformation of austenite as manganese or nickel. Nevertheless, Chromium Steels (for example, 11% CR, 0.20 C) are harder than the corresponding nickel or manganese steels of the same type of heat treatment. The electric conductivity of iron and steel is reduced about 70% by 10% Cr; the thermal conductivity is reduced 50%.

WELDING LOWER CHROMIUM STEELS

Mechanical Properties

No comprehensive investigation of the mechanical properties of welded plain chromium steels has been made. In Orr's[1] tests, specimens $^1/_2$ x $1^1/_2$ inches cross section cut from a butt weld made with a special electrode (current slightly higher than for mild steel) in plates containing 0.35 C, 1.1 Mn, 0.6 Cr (yield strength = 58,700 lb./in.^{2}, tensile strength = 91,500 lb./in.^{2}) had a tensile strength of 94,500 lb./in.^{2} unmachined and 100,000 lb./in.^{2} with weld machined flush. Roller bend tests with a plunger $1^1/_2$ inches diameter resulted in cracks at 60° and an elongation of 20% in 4 inches. Blackwood[2] found that weld-metal containing 0.10 C, 0.70 Mn, 0.05 Si, 0.34 Cr deposited by a covered electrode had an average yield strength of 56,600 lb./in.^{2}, tensile strength 70,800 lb./in.^{2}, elongation 10.8% in 8 diameters, 25.2% reduction of area, and 43 ft.-lb. Izod value. The tensile specimens were $^1/_4$ to $^1/_2$ inch diameter machined from all-weld-metal.

In 1930 Kinzel and Miller[3] oxyacetylene welded an experimental tank 93 inches long, 24 inches i.d., $^3/_8$-inch wall using a Mn-Mo high-strength rod (No. 22, no details). The plate welded easily and was of electric furnace steel containing 0.28 C, 0.90 Mn, 0.33 Si, 0.31 Cr. The tank was heated to 900° C. after welding and was furnace cooled. In a hydrostatic test the tank failed at a fiber stress of 78,500 lb./in.^{2} with a permanent increase in circumference of $3^3/_4$ inches. A free-bend weld specimen cut from the ruptured tank developed an elongation of 22 to 25% (no details). Butt welds made by Hackett[4] with iron wire in steel containing 0.30 C, 0.50 Cr, had a yield strength = 67,000–73,000 lb./in.^{2}; tensile strength = 105,000 lb./in.^{2}; 10% elongation in 2 inches over weld, fracture outside weld. The base metal in the as-drawn state had a yield strength = 101,000 lb./in.^{2}; tensile strength = 110,000 lb./in.^{2} Brazed lugs on this steel withstood 19,155 cycles at an alternating stress of ±40,300 lb./in.^{2}, or 62,240 cycles at ± 35,800 lb./in.^{2} at 400 r.p.m.

Tensile tests by Csilléry and Péter[5] on rail steel (0.50 C, 0.30 Si, 0.65 Mn, 0.80 Cr, tensile strength = 129,000 lb./in.^{2}, elongation = 14% in 5 diam., reduction of area = 43%, notch impact value (cross section of fracture = 14 x 14 mm., notch 4 mm. diameter, 7 mm. deep) = 1.6 mkg./cm.^{2}; annealed 700° C.) welded at the root with a dipped electrode containing 0.12 C, 0.40 Mn, trace Si (nitrides visible in weld), the upper layers being deposited with a bare electrode, 0.16 inch diameter, containing 1.00 C, 0.15 Si, 0.30 Mn, 1.00 Cr, 1.50 W (deposited metal contained 0.61 C, 0.07 Si, 0.26 Mn, 0.78 Cr, 0.95 W) showed that the tensile strength of the composite butt weld was 41,700 lb./in.^{2}, elongation = 7.3% in the length of the weld; reduction of area = 14%; notch impact value (notch in root) = 1.5 mkg./cm.^{2} Base metal, heat-affected zone, and the alloyed layers of the weld were 230–255 Brinell. The unalloyed layers were 105 Brinell. Alloyed weld and heat-affected zone consisted of fine pearlite. Using the Spindel apparatus the investigators found that the wear resistance of the weld was greater than 50% of base metal. Eckman[6] reports a tensile strength of 95,000–96,000 lb./in.^{2} in a flash-welded steel containing 0.30–0.35 C, 0.65–0.80 Mn, 0.90–1.10 Cr, 0.20 Si (tensile strength unwelded was 100,000 lb./in.^{2}).

By way of summary it may be concluded that up to 0.3 Cr and 0.30 C the welds have the same ductility as plain carbon steels of the same carbon content. The scanty information at hand does not suggest that welded plain chromium steels having higher chromium or carbon

contents (up to 1% Cr) will be unusually ductile. According to Kinzel[7] (1936), chromium carbide is the essential strengthener in all alloy steel welding rods.

Hardness

The hardness of welded plain chromium steel has been studied only in the higher carbon ranges. Bergsma[8] found that arc welds in steel (0.68 C, 0.28 Mn, 0.16 Cr, 210 Brinell) made with Railo electrodes (no details) were 350 Brinell; the heat-affected zone was 400 Brinell. Porous deposits in steel containing 0.60–0.70 C, 0.30–0.40 Mn, 0.10–0.20 Si, 3.25–3.75 Cr, 10 C Rockwell, made with an electrode of the same analysis, according to Lubovsky,[9] were 55 C Rockwell, the heat-affected zone was 30 C Rockwell. The structure appeared martensitic. Using a coated electrode depositing metal containing approximately 3% Cr, 0.6 C, Lubovsky found that the weld in a steel containing 0.95–1.05 C, 0.25–0.35 Mn, 0.15–0.25 Si, 0.10 Cr max., 10 C Rockwell, was 33 C Rockwell; the heat-affected zone was 31 C Rockwell. Bainbridge[10] mentioned that the hardness of a rail (1% Cr steel, 232 Brinell) in the vicinity of an oxyacetylene welded copper bond was 308 Brinell. Unfortunately the charts prepared by Rapatz[11] showing the hardness of gas welds in iron-chromium alloys up to 30% chromium using filler rods with 0.1, 0.2 or 1.5 C are unaccompanied by any details which would have made the charts of value.

General Observations

In 1922 Diegel[12] observed that chromium up to 0.15% (upper limit not determined) had no effect on the oxyacetylene welding of mild steel. Smallman-Tew[13] (1937) regards the steels containing 0.20 C, 0.5 to 1.0 Cr (with 0.7 Mn and 0.3 Cu) as the best weldable high tensile steel, along with 1.5 Mn steel. On the other hand, *Metallurgist*[14] stated that high-tensile steel for welding should be based on copper and silicon, rather than on air hardening elements, such as chromium, and manganese. To avoid welding cracks in low-alloy structural steel avoid chromium, is Van Dam's[15] advice, which was followed by the Royal Dutch Marine in 1936. According to Hatfield,[16] cracks in welded chromium steels increase as carbon and chromium contents increase. Probably air hardening is considered the cause of cracks. M. C. Smith[17] cautions that as little heat as possible should be used in the welding of any chromium steel and adds that carbon steels containing chromium are subject to abnormal grain growth during welding. In the absence of support for the latter statement, it may be dismissed as lacking authority. In Harris'[18] opinion temper brittleness may be created in some welded chromium steels by stress annealing (no details). Doubtless, slow cooling from the heat-treating temperature is responsible for temper brittleness. Armstrong[19] proposed the addition of titanium to air hardening chromium steels for the purpose of possibly eliminating some welding difficulties. Ruder[20] observed that a tough oxide film, which is disadvantageous in fusion welding, is formed on chromium steels. For some unexplained reason, chromium in bare electrodes tends to produce porosity at the fusion zone, according to Jennings.[21]

Steels containing more than 0.05 Cr are not suitable for forge welding, according to Speller.[22] Forge welding, Howe[23] found, was difficult with a steel containing 0.25 Cr on account of refractory oxide.

Without supplying details, Burgess and Aston[24] stated that up to 20% Cr, pure iron alloys can be resistance butt welded. If care was exercised, an alloy containing 20 Cr, 4 Si could be resistance butt welded. Additions of W or of Mn + Mo to the Cr-Si alloy prevented resistance butt welding. Andrews and Welsh[25] illustrate burning in a resistance butt weld in a martensitic chromium steel (no details) and conclude that chromium steels in general tend to burn in flash welding. The Netherland Standards[151] for Welding in Shipbuilding specify that the steel must contain no chromium.

Chromium steels have been recommended on several occasions for surfacing worn rails. Golling[26] uses a rod containing 0.9 C, 0.6 Cr, and the Netherlands Railways[27] uses an oxyacetylene rod depositing steel containing 0.37 C, 0.85 Mn, 1.10 Cr, 0.49 Si, 0.15 Ni. In Germany, where the rails are usually 300 Brinell, according to Frankenbusch,[28] a good oxyacetylene rod for building up contains 0.84 C, 0.40 Mn, 0.017 Si, 0.42 Cr (285 Brinell as deposited, 310–315 Brinell in service). Deglon's[29] hard-surfacing electrode (1.03 C, 0.7 Mn, 1.18 Cr) deposits steel containing 0.4 C, 0.6 Mn, 0.7 Cr. Deposition on a rail preheated to 500° C. results in a much larger proportion of ferrite in the deposit than on a cold rail, the hardness being 450 Brinell on the cold rail and 300 Brinell on the preheated. According to R. Smallman-Tew (private communication, May 1938), some rail surfacing electrodes used in England deposit metal containing 0.4 C, 1.0 or 2.0 Cr, 0.10 Mn. If the rail is not preheated, the Brinell hardness of the deposit is 450 (1.0 Cr) or 530 (2.0 Cr). If the rail is preheated to 250° C., the Brinell hardness of the deposit is 270 (1.0 Cr) or 320 (2.0 Cr). Preheating is customary to prevent cracks in the heat-affected zone of the unalloyed rails. The surfacing of dies (S. A. E. 5150 and steel with 0.71 C, 0.23 Mn, 0.15 Si, 3.27 Cr) by arc welding is satisfactory, according to two Russian investigators,[30] if the dies are annealed. Cast rods for building up airplane tail skids are listed in Table 1.

Table 1—Cast Welding Rods for Building Up Airplane Tail Skids. Johnson[31]

C	Mn	Si	Ni	W	Cr
3.5	10.0	2.0	3.0	..	3.0
4.0	6.0	1.0	..	..	30.0
3.5	0.2	0.5	..	16.0	10.0

Recovery

Molten chromium steel requires protection from strong oxidizing agents if loss of chromium is to be avoided. Consequently it is not unexpected that complete recovery of chromium from the filler rod is not achieved in some welding processes. Deglon[29] found that an electrode (probably bare) containing 1.03 C, 0.7 Mn, 1.18 Cr deposited metal containing 0.4 C, 0.6 Mn, 0.7 Cr. According to Dixon,[32] less than 0.25 Cr is lost in depositing a heavy covered electrode containing 4–Cr, 0.5 Mo, 0.15 C.

Using the materials listed in Table 24 of the review of literature on Welding Nickel Steels, Losana and Jarach[33] found that recovery of chromium from coatings, Table 2, depends on the chromium content if the coating is very low in Si and Mn. If Si and Mn, which did not improve the recovery, were present, the recovery of chromium varied between 1/4 and 1/2, and did not depend on chromium content.

The composition of the weld-metal deposited by a coated electrode in welding a steel containing 0.60–0.70 C, 0.30–0.40 Mn, 0.10–0.20 Si, 3.25–3.75 Cr was determined by Lubovsky,[9] Table 3. The core rod of the electrode contained 0.84 C, 3.35 Cr, 0.26 Mn, 0.20 Si. The recovery of chromium was 77% in the electrode whose coating contained no ferrochromium. Calcium fluoride seemed to decrease the chromium recovery, whereas graphite increased it. Noderer[34] reported that a bare electrode containing 3.37 C, 9.20 Mn, 32.35 Cr deposited

Table 2—Recovery of Chromium from Coated Mild Steel Electrodes. Losana and Jarach[33]

No.	(Mn)	(Si)	(Cr)	$(Cr)^1$	(C)	[Mn]	[Si]	[C]	[Cr]	$[Cr]/(Cr)^1$	Brinell Hardness
1	7.26	2.77	5.18	2.1	2.94	0.29	0.03	0.03	0.49	0.23	162
2	7.10	2.63	10.02	4.0	2.80	0.28	0.05	0.05	1.24	0.31	168
3	6.96	2.51	21.40	8.5	2.77	0.32	0.04	0.08	3.76	0.44	194
4	13.94	2.60	5.02	2.0	2.64	0.48	0.13	0.04	0.86	0.43	174
5	13.71	2.42	10.64	4.2	2.72	0.49	0.14	0.06	1.12	0.27	181
6	13.44	2.37	20.76	8.3	2.48	0.52	0.18	0.09	3.24	0.39	...
7	28.36	2.46	5.34	2.1	2.52	1.15	0.29	0.11	0.98	0.47	...
8	28.02	2.54	11.10	4.4	2.38	1.22	0.34	0.15	1.06	0.24	190
9	27.81	2.32	21.14	8.4	2.60	1.27	0.40	0.24	3.10	0.37	244
10	7.34	5.80	5.62	2.2	7.06	0.39	0.56	0.08	0.95	0.43	...
11	5.18	5.42	10.94	4.3	6.98	0.42	0.47	0.12	1.68	0.39	192
12	7.00	7.18	22.30	8.9	7.12	0.46	0.51	0.15	2.98	0.34	...
13	7.12	9.86	11.18	4.4	6.80	0.45	0.70	0.19	1.71	0.39	200
14	6.94	18.02	21.46	8.5	16.52	0.59	1.15	0.22	2.70	0.32	230
15	7.48	0.38	2.34	0.9	16.04	0.48	0.01	0.05	0.34	0.38	...
16	7.32	0.37	10.27	4.1	15.87	0.55	trace	0.09	1.88	0.46	204
17	0.64	0.46	5.21	2.1	2.78	0.07	..	0.02	0.50	0.24	...
18	0.58	0.29	10.48	4.2	2.63	0.08	..	0.03	1.37	0.33	...
19	0.42	0.41	16.34	6.5	2.81	0.09	..	0.06	2.70	0.41	...
20	0.61	0.35	21.80	8.7	2.49	0.12	..	0.09	4.38	0.50	...

( ) = Weight % constituent in coating. $(Cr)^1$ = Percentage of chromium calculated on basis of core rod of electrode
[ ] = Weight % constituent in deposit. $[Cr]/(Cr)^1$ = Approximate recovery of Cr.
The ferrochromium contained 59.82 Cr, 2.18 C, 0.64 Mn, 0.61 Si, 0.026 P, 0.048 S.

Table 3—Recovery of Chromium from Coated Electrodes. Lubovsky[9]

Composition of Coating, Expressed in Parts						Composition of Weld-Metal, %			
$CaCO_3$	Fe_2O_3	CaF_2	Ferro-manganese	Ferro-chromium	Graphite	C	Cr	Mn	Si
55	30	..	10	..	..	0.32	2.57	0.32	..
55	30	..	10	5	..	0.29	3.30	0.32	..
55	..	30	10	5	..	0.55	2.98	0.20	0.13
55	..	30	10	5	15	0.74	3.10	0.6	0.20

metal containing 0.83 C, 6.44 Cr, 1.68 Mn, the electrode being positive. The recovery of chromium was only 20%. According to Crepaz and Lops,[35] 0.3–0.4 Cr can be introduced into oxyacetylene welds by coating the filler rod with ferrochromium. Without supplying details, Lohmann[36] stated that chromium is lost to a great extent from a coated electrode containing 0.1 C, 0.4 Cr, 0.6 Cu.

Pick Up

To what extent plain carbon steel weld-metal will absorb chromium from chromium steels cannot be stated at the present time. Haardt[37] deposited bare and covered low-carbon electrodes in one or two layers on a steel containing 0.1 C, 0.4 Mn, 0.2 Si, 3.5 Cr but was unable to determine the pick up because the deposits were porous and full of slag, especially the bare electrode deposits. Apparently there was much less diffusion of Cr in two-layer deposits than in similar tests with Si, Mn, Cu or Ni.

Flame Cutting

With up to 3.5 Cr there is no difficulty in burning the metal during flame cutting, according to Kinzel and Crafts.[38] The slag flows freely and there is little danger of cracking. The steels with high carbon and chromium (up to 10% Cr) are air hardening and must be heat treated to soften the kerf.

For relatively small sections of simple shape, according to W. Crafts (private communication, June 1938), the maximum safe carbon content is not much lower than for plain carbon steel, that is, 0.30 to 0.35 C for both 1 and 3% Cr steels. The comparable carbon contents for higher chromium steels are appreciably lower. If the shape is unfavorable, or the cross section is large, or the carbon content exceeds the safe limit, preheating or retarded cooling, is advisable.

A detailed study of hardness in flame cut chuck steel (0.20 C, 0.20 Cr, 0.97 Mn, 0.046 Si, 0.055 P, $1^5/_{16}$ inch thick, 168–174 Brinell) by Yatsevitch[39] showed that the depth of the heat-affected zone was 0.052 inch except in the top $^1/_4$ inch of the cut where the depth reached 0.156 inch. The maximum Brinell hardness was 303 at the bottom edge, 215–223 in the middle of the cut, and 244 at the top edge (torch side). Evidently the cooling rate was slowest in the middle of the thickness although there the cut is backed on all sides by cold metal. The cutting was done with city gas at 10 lb. pressure (oxygen pressure = 27 lb.). The cutting speed was 8 inches per minute and the cutting orifice was No. 58 drill. Risers of 4–7 Cr castings can be oxyacetylene flame cut if the casting is preheated to 480° C. (900° F.), according to Priestley.[40]

Only if preheated white hot can pure chromium be oxyacetylene flame cut, according to Wiss.[41] Steels with 1.5 Cr are easily flame cut but, even if preheated, steels with 10–20 Cr cannot be cut. Wiss[42] also found that the cut edge of steels with 2.2 Cr, 0.3 C or higher is martensitic (thickness not stated). Oxyacetylene cut steel with 2.1 Cr, 1.2 C was ledeburitic at hand-cut edges, but machine cut edges were not ledeburitic. De Jessey[43] was able to machine flame cut rolled steels 1 inch thick containing 0.71 C, 0.22 Si, 0.28 Mn, 1.95 Cr, and 0.24 C, 2.90 Si, 0.41 Mn, 3.73 Cr, but was unable to cut steel containing 0.26 C, 2.54 Si, 0.42 Mn, 6.20 Cr. There was no drag at cutting speeds of 25–35 ft./hr. but the cut surface was rough. Smoother cuts were obtained at 55 ft./hr. but the drag was about $^1/_8$ inch. The depth of the heat-affected zone determined by microstructure was only 0.03–0.04 inch at 45–55 ft./hr. compared with 0.06 inch in mild steel at the same speed. Perhaps the high critical points of the chromium steels account for the difference. The effect of silicon was not discussed. The 6.2% Cr steel could not be cut even if preheated or if the oxygen pressure was increased or the orifice enlarged. An English welding magazine[44] found steels containing more than 8% Cr impossible to flame cut, because the "chrome" slag opposed the propagation of the oxidation of iron. Séférian and Leroy[45] have determined the corrosion resistance of

flame cut Cr-Cu steel (0.20 C, 0.52 Cr, 0.57 Cu, 0.70 Mn, 0.27 Si) in saline solution and 20% H_2SO_4 (see review of literature on Welding Copper Steels).

As would be expected, chromium steels yield high hardnesses in flame hardening. For example, Shorter[46] reported 600 Brinell on the flame hardened surface of a steel containing 0.43 C, 1 Cr.

WELDING 4–6% CHROMIUM STEELS

The low-carbon steels with 4 to 6 Cr and usually 1/2% Mo are widely used as welded oil still piping. As Hodge[47] points out, Table 4, the hardness of these steels

Table 4—Effect of Maximum Heating Temperature on the Brinell Hardness of Air Cooled 4–6 Cr, 1/2 Mo Steel. Hodge[47]

Carbon Content, %	Temperature from Which Steel Is Air Cooled 815° C.	870° C.	925° C.	Welding Temperature
0.23	159	393	444	Approximately 450
0.12	143	350	363	Approximately 450
0.05	131	253	302	Approximately 450

on air cooling is closely related to the maximum temperature attained. If the steel is heated to the welding temperature, the carbon content has no effect on the hardness, which is high and, as usual, is associated with brittleness. The hardness of weld-metal in an arc weld in 4–6 Cr, 1/2 Mo steel (150 Brinell) made with electrodes of the same analysis may be 340–430 Brinell. The hardness progressively decreases in the heat-affected zone as the distance from the weld increases. Preheating locally or entirely to 150–200° C. (300–400° F.) is necessary to prevent air hardening and cracking during welding. Immediately after welding and without allowing the part to cool below preheating temperature, the welded part must be annealed. Annealing for 4 hr. at 700° C. (1300° F.) followed by air cooling reduces the hardness of the weld to 200 Brinell. If the part is annealed at 870° C. (1600° F.) and cooled at the rate of 28° C. per hr. (50° F. per hr.) to 650–700° C., then air cooled, the hardness of the weld is reduced to 140 Brinell. These results are in agreement with the fact that the end of the critical range on heating is 830–870° C. for the 4–6 Cr steels. The increase in air hardening as the temperature is increased is related perhaps to the progressive solution of Cr and Mo from their carbides even in low-carbon steels. A full annealed (870° C.) A. S. M. E. free-bend specimen 3/4 inch thick developed 67% elongation. Micrographs at 250 × revealed coarse grain in the untreated weld-metal. No change except tempering was produced by heating to 700° C., but after being heated to 870° C. the specimen had a fine-grained ferrite-pearlite structure in weld and heat-affected zone. Hodge mentioned that titanium or aluminum may be added to the weld to decrease excessive air hardening. According to J. C. Hodge (private communication, June 1938), it is difficult to transfer titanium and aluminum across the arc without excessive loss due to their great affinity for oxygen. The recovery of columbium in the deposited metal is relatively high. Consequently, columbium is preferred for oxyacetylene rods or electrodes of 4–6 Cr type, if decrease in the excessive air hardening of the weld-metal is desired.

The oxyacetylene welding of the medium chromium steels is described by Priestley.[40] Using a rod containing 6–8 Cr with columbium (no details about composition or preheating), Priestley[40] found that blowpipe annealing (1 or 2 minutes at 800–900° C.), Table 5, yields good results in 1/4-inch plate containing 0.07 C, 5.51 Cr, 0.56 Mo, 0.37 Ti. Columbium and titanium reduce the required annealing time. Dawson[48] states that the tendency to brittleness in the weld-metal of higher carbon grades of 5 and 9% Cr can be alleviated by local torch annealing for 3 min. at 650–760° C. (1200–1400° F.). Schöne[49] favors oxyacetylene welding for 4–6 Cr, 1/2 Mo superheater tubing. The joint is heated 15 min. at 900° C., then cooled slowly to 500° C. and held for 1 hr.

Table 5—Mechanical Properties of Oxyacetylene Welded 4–6 Cr, 1/2 Mo, 1/2 Ti Steel. Priestley[40]

Specimen	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 2 Inches	Free-Bend Angle, Degrees
As-Welded	30,000 to 40,000	55,000 to 65,000	4 to 8	45 to 90
Blowpipe Annealed	30,000 to 40,000	55,000 to 65,000	8 to 12	120 to 180

The typical tensile properties of welds in steel containing 0.10 C, 0.30 Mn, 0.20 Si, 5.21 Cr made with an electrode of similar analysis, Table 6, convinced Jennings[21] of the necessity for full annealing. Preheating at 150–260° C. is essential except for very thin sheet. Electrodes of the same analysis as base metal with relatively low currents are best, although 18–8 electrodes may be used. The 18–8 electrodes do not eliminate air hardening and brittleness in the heat-affected zone, and 18–8 weld-metal has about 50% greater thermal expansion than 4–6% Cr steel. The recommended heat treatment for base metal seriously affects the corrosion resisting properties of 18–8 weld-metal. Davis's[50] instructions are in agreement with those recommended by Jennings and Hodge. A shielded arc electrode (electrode positive) is used under the conditions given in Table 7. The composition of the electrode is not given.

Table 6—Tensile Properties of Arc-Welded 4–6 Cr Steel. Jennings[21]

Specimen	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 2 In.	Reduction of Area, %
Unwelded Base Metal	35,000 to 40,000	65,000 to 70,000	35 to 40	65 to 75
As-Welded	60,000	90,000	10	12
Welded and Annealed at 870° C.	40,000	67,000	35	65

Table 7—Welding Conditions for 4–6 Cr Steel Shielded Arc Electrodes. Davis[50]

Diameter of Electrode, Inch	Current, Amps.	Arc Voltage
1/8	75–100	22–23
5/16	125–200	26–27

It is Johnson's[51] experience that if the welded part can be stress annealed at 590–650° C. an electrode of the same composition as base metal should be used, whether welding 4–6 Cr steel (with or without 1/2 Mo) to itself or to plain carbon steel. Otherwise an 18–8 (KA2S) electrode is called for unless the operating temperature is to exceed 530° C., in which case an 18–8-Mo electrode is best. Newell[52] mentions that 18–8 electrodes have been successful in seal welding 4–6 Cr steel flanges on hot oil lines.

As a general rule 4–6 Cr steel for welding should contain less than 0.12% carbon. In common with Hodge and Chapman,[53] Newell emphasizes the importance of preheating and of annealing immediately after arc welding.

The heavy coated electrode recommended by Dixon[32] for welding 4–6 Cr steel contains 0.15 C max., 4–6 Cr, 0.5 Mo, is welded positive. Less than 0.25 Cr is lost during welding. The scarves are preheated to 260–315° C. (500–600° F.) before being tacked. The sequence and number of layers are the same as in plain carbon steel but the scarves must never fall below 150° C. (300° F.). Satisfactory vertical and overhead welding is possible. The structure of an annealed weld is better than base metal and tensile specimens (no reduced section) usually fail in the weld with considerable necking. Welds in 4–6 Cr steel pipe with $^3/_4$-inch wall may be bent 180° around $^3/_4$-inch pins without cracks after heat treatment.[54] Welding of sections up to inch thick in 4–6 Cr, $^1/_2$ Mo steel is satisfactory, according to Moses,[55] but thicker sections create difficulty with air hardening and inspection.

The process approval tests of the U. S. Navy Bureau of Engineering quoted by Stewart[56] are based on the factors which have been discussed. The requirements of the specimens from the test plate, Fig. 1 are shown in Table 8. Any heat treatment after welding shall be ended by stress annealing at not less than 650° C. (1200° F.) for not less than 4 hr., followed by slow furnace cooling to 260° C. (500° F.), then air cooling. Preheating is at 320 to 430° C. (600 to 800° F.), according to Chadwick.[57]

The addition of 0.5% columbium to 4–6 Cr steel (0.06–0.08 C) to prevent air hardening has been recommended by Wilkinson[58] on a number of occasions. Without supplying details, Wilkinson states that the heat-affected zone of a weld in 4–6 Cr steel (137 Brinell) made with a 24 Cr-12 Ni rod was 311 Brinell if no Cb was added to the steel, but was only 166 Brinell if Cb was present. A similar effect is achieved by titanium, according to Williams,[59] in 4–6 Cr steel with or without Mo. No heat treatment is required after welding.

WELDING OTHER MEDIUM CHROMIUM STEELS

The welding of the lower chromium, low-carbon steels used for purposes similar to the 4–6 Cr steels is described by Newell.[60] Steels containing 0.15 C max., 0.30–0.60

Table 8—Requirements of U. S. Navy for Arc-Welded 4–6 Cr Steel. Stewart[56]

	C	Mn	Si	Cr	Mo	S	P	Yield Strength, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation, % in 2 In.
Forged Base Metal	0.15 max.	0.50 max.	0.50 max.	4.0–6.0	0.45–0.65	0.040 max.	0.040 max.	25,000 min.	58,000 min.	30 min.
All-Weld-Metal	..	..	..	3.0–5.0	0.40–0.65	...	...	30,000*	....	20 min.

* = Stress showing 0.0001 inch per inch permanent extension after removal of load.
Transverse Tension specimen: failure shall occur in base metal at 58,000 lb./in.^{2} min. or in weld at 65,000 lb./in.^{2} min.
Bend Specimen: elongation = 30% min.

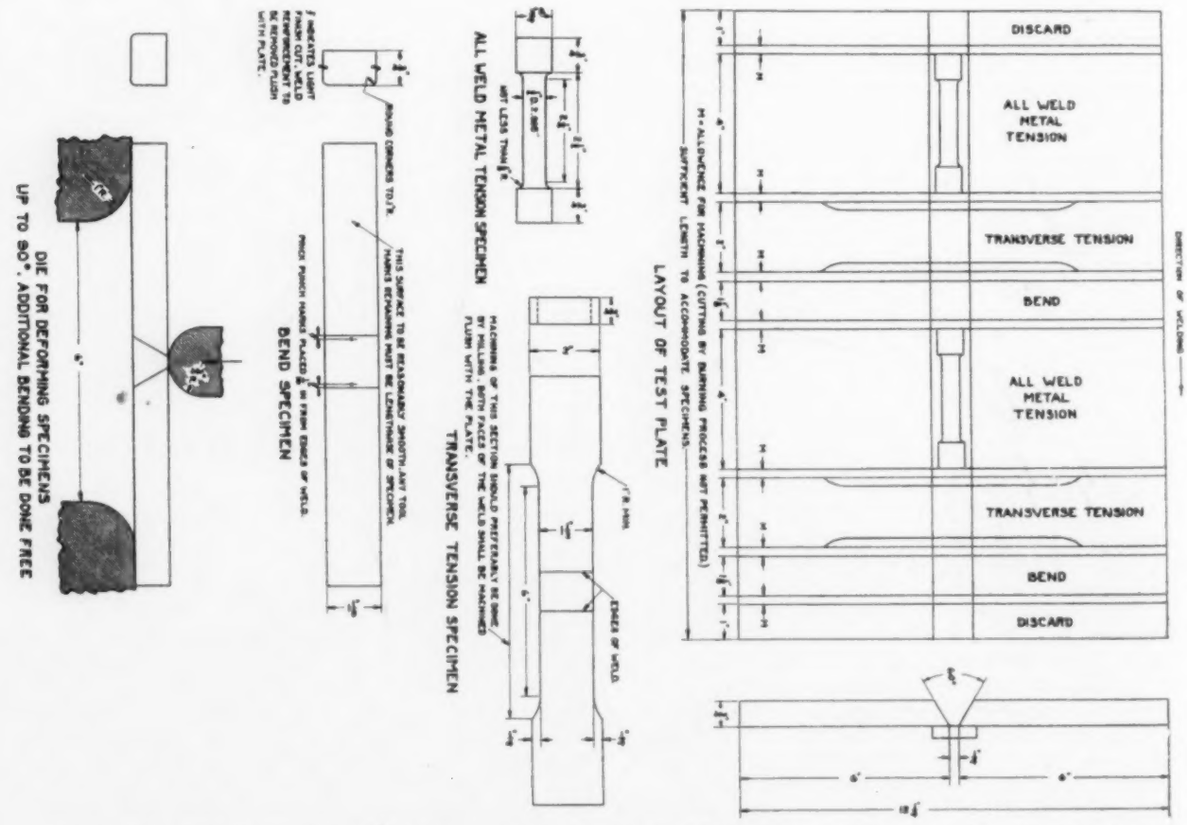

Fig. 1—U. S. Navy Bureau of Engineering Process Approval Plate for Welding 4–6 Cr, $^1/_2$ Mo Steel. Stewart[56] (see Table 8)

Mn, 0.50 Si max., and either 1.75–2.25 Cr, 0.40–0.60 Mo, or 2.75–3.25 Cr, 0.80–1.00 Mo (Croloy steels) are air hardening and must be preheated to at least 150° C. (300° F.). Since the heat-affected zone in the as-welded condition is 275–375 Brinell, the welds should be either annealed at 830° C. (1525° F.) and cooled in the furnace not faster than 33° C. per hr. (60° F. per hr.), or stress annealed a short time at 720–750° C. (1325–1375° F.) and air cooled. The electrode should deposit metal of same analysis as base metal; a plain carbon steel electrode should be used only if the weld is to be made between the chromium steel and mild steel. Oxyacetylene and atomic hydrogen processes are entirely satisfactory. Peening is not necessary. According to Williams,[59] steel containing 0.4–0.6 C, 0.5–1.0 Si, 2.25–2.75 Cr (Sicromo) is subject to air hardening and must be welded with the same care exercised for 4–6 Cr steel. Chadwick[57] recommends stress relieving at 650° C. for welded steel containing 0.07 C. 0.42 Mn, 0.72 Si, 1.25 Cr, 0.54 Mo.

Covered electrode welds in 0.12-inch plate containing 9 Cr, 3 Si had the mechanical properties shown in Table 9, prepared by Schottky.[61] The bend specimens only were not machined. The welds had the same strength as base metal but the ductility was inferior. Ductile welds were made by oxyacetylene or shielded arc in 6 Cr-1 Al steel. A steel with 0.5 C, 8.5 Cr, 3.5 Si (Silcrome) was applied by Meriam[154] as a surface layer on forged molybdenum steel (no details) to form the seat of a gas engine valve. The atomic hydrogen process was used.

Table 9—Mechanical Properties of Arc Welds in 9 Cr-3 Si Steel. Schottky[61]

Electrode	Yield Strength, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation, % in $11.34\sqrt{A}$	Bend Angle, Degrees	
9 Cr-3 Si	72,500	98,000	6.2	124	Heat treated
Austenitic	78,000	98,000	9.6	130	Not heat treated
Unwelded	72,500	98,000	21.4	>180	.....

A = Cross-sectional area of specimen.

The single-V butt welding of the steels in Table 10 in the form of superheater tubing, presumably by the oxyacetylene process, was studied by Christmann[62] using filler rods of base metal or of austenitic steel. Welds made with rods of base metal were valueless; they were porous, cracked and full of slag. The same welder using austenitic rods had excellent results. The microstructure was free from slag and the welds successfully passed an internal hydrostatic test. A later development by Schiffler and Wingerath, according to Dr. N. Christmann (private communication, May 1938), has been the replacement of the austenitic chromium-nickel rods by rods of ferritic base metal containing silicon, chromium and other elements to secure resistance to scaling, but free from nickel and aluminum. The ferritic rods produced welds free from slag inclusions. Fluxes and coating were developed (no details) to permit the use of a rod depositing metal containing aluminum together with chromium and silicon.

Table 10—Steels Welded by Christmann[62]

Steels								Filler Rods		
C	Si	Mn	P	S	Cr	Mo	Al	C	Cr	Ni
0.09	0.4	0.51	0.011	0	6.90	0.39	1.88	0.14	18.41	8.94
0.09	0.4	0.52	0.013	0	6.94	0.35	2.75	0.07	26.46	20.12

WELDING CHROMIUM-VANADIUM STEELS

There has been a great deal of interest in the low-alloy chromium-vanadium steels. This section summarizes available information on mechanical properties of welds and on the peculiarities of welding the Cr-V steels.

Mechanical Properties

Corneil[63] found that soft annealed tubes containing 0.22 C, 0.73 Mn, 0.97 Cr, 0.15 V, 2¼ inches i.d., ½-inch wall had a yield strength of 78,500–89,500 lb./in.^{2}, tensile strength of 84,600–89,500 lb./in.^{2} (fracture outside weld) when oxyacetylene welded (90° V butt, 5 layers) with ⅛-inch rod of the same analysis as base metal. The oxyacetylene welded specimens were very brittle and could not be bent more than 5°. The unwelded steel had a yield strength of 63,500 lb./in.^{2}, tensile strength 85,500 lb./in.^{2}, elongation 29.5% in 2 inches. Five-layer metal arc welds made with 5/32-inch electrodes had a yield strength of 56,000–58,000 lb./in.^{2}, tensile strength 68,000–75,000 lb./in.^{2}, elongation 6 to 11% in 2 inches with fracture in weld. Arc-welded strips could be bent nearly 180° without fracture. The arc welds required no heat treatment and successfully passed an internal pressure test (no details).

Although supplying no details, Jennings[21] states that arc-welded Cr-V steel (0.18 C, 0.40 Mn, 0.15 Si, 0.92 Cr, 0.16 V) has a yield strength of 65,000 lb./in.^{2}, tensile strength 90,000 lb./in.^{2}; elongation 22% in 2 inches; reduction of area 46%. The welds were made with a carbon-molybdenum electrode. Tris and Kapetensky[64] (1919) determined the tensile strength of gas and arc welds in a steel containing 0.40 C, 0.65 Mn, 0.95 Cr, 0.18 V, Table 11. The welds were made in beveled bars, 1 inch diameter, ¼-inch root spacing, and were machined to tensile specimens 0.505 inch diameter. A bare electrode (0.03 C, 0.12 Mn) was used as well as a nickel steel filler rod (0.12 C, 0.45 Mn, 3.41 Ni) for oxyacetylene welding. The heat-treated oxyacetylene weld was oil quenched from 870° C., tempered at 540° C., air cooled. The results show that a high strength steel can be ruined by bare electrodes.

Table 11—Tensile Properties of Oxyacetylene and Arc (Bare Electrodes) Welded Cr-V Steel. Tris and Kapetensky[64] (1919)

Elastic Limit Lb./In.^{2}		Tensile Strength, Lb./In.^{2}			
Gas Welded	Arc Welded	Unwelded	Gas Welded	Arc Welded	Gas Welded and Heat Treated
30,000	none	107,750	71,450	30,500	82,100

Tensile tests of oxyacetylene butt welds in sheet 0.036 inch thick containing 0.14 C, 0.50 Mn, 0.028 S, 0.04 P max., 0.77 Cr, 0.23 V were made by Sisco and Boulton.[65] The filler rods were 1/16 inch diameter. The low-carbon steel rod was copper coated and contained 0.03 C, 0.48 Mn. The uncoated Cr-Mo steel rod contained 0.28 C, 0.61 Mn, 0.04 P max., 1.14 Cr, 0.95 Mo.

The results in Table 12 show that the plain carbon steel filler rod is as good as the Cr-Mo rod for joints that are not heat treated. The results from the heat treated joints were erratic. Fracture in the weld coincided with poor mechanical properties, the tensile strength being only 70% of the specimens that fractured remote from the weld. The microstructure revealed that the junction of weld with base metal was unusually abrupt more so than in similar welds made in S. A. E. X4130. The thinness of the junction zone was accentuated in the speci-

Table 12—Tensile Tests of Oxyacetylene Welded Cr-V Sheet. Sisco and Boulton[65]

Heat Treatment	Filler Rod	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 2 In.	Elongation, % in 8 In.	Location of Fracture	Character of Fracture	Number of Tests	Width of Specimen, In.
None	Plain Carbon	35,800 to 39,050	51,900 to 60,400	13.5 to 15.0	...	3/4 to 1 inch from weld	Diagonal	2	3/4
None	Cr-Mo	38,700 to 39,500	57,500 to 61,800	10.0 to 13.5	...	3/4 to 1 1/2 inch from weld	Diagonal	2	3/4
Water Quenched 885° C. (1625° F.); Drawn 540° C. (1000° F.)	Cr-Mo	66,600 to 93,300	88,700 to 142,500	0.50 to 3.5	0.50 to 2.0	4 remote from, 3 in weld	Square at weld, diagonal outside	7	1/2
Water Quenched 885° C. (1625° F.); Drawn 680° C. (1250° F.)	Cr-Mo	68,700 to 77,000	85,350 to 130,600	0.50 to 4.5	0.50 to 4.5	2 at weld, 3 next to weld, 2 remote	Square at weld, diagonal outside	7	1/2
Water Quenched 885° C. (1625° F.); Drawn 540° C. (1000° F.)	Unwelded Sheet	108,000	130,000	4	...	...	...	...	...

mens drawn at 680° C., and was believed to account for the tendency of the specimens drawn at that temperature to fail in the weld. The Cr-Mo steel rod was not considered appropriate for welding Cr-V sheet.

Butt welds in 16 and 18 gage sheet (S. A. E. 6130) were made by Hird[66] with a rod containing 0.06 C, 0.15 Mn, 0.08 Si. Both oxyacetylene and arc welds, the latter with light coated electrodes 1/16–3/32 inch diameter, had a tensile efficiency of over 100% with bead on or off. The welds could be bent 180° in most cases, but if the bead was on the tension side, the bend angle was reduced to 50° in some specimens. In 1921 Eschholz[67] made 60° V reinforced butt welds with lime coated 3 1/2% nickel steel electrodes 3/16 inch diameter, 175 amps., in bars 5/8 x 2 inches containing 0.48 C, 0.85 Mn, 1.0 Cr, 0.18 V. Weld and base metal were forged to 0.408 x 1.625 and oil quenched from 875° C. and fractured in base metal at a tensile strength of 88,900 lb./in.² Another specimen welded in the same way but at 150 amps., forged, annealed at 900° C., then oil quenched from 875° C. and drawn at 250° C. had a tensile strength of 107,000 lb./in.,² elongation 14.4% in 1 inch, reduction of area 14.2% with fracture partly in weld-metal.

According to Strauss,[18] weld-metal containing 0.25–0.30 C, 0.5–0.7 Mn, 0.2–0.3 Si, 1.0 Cr, 0.15–0.20 V has a yield strength of 65,000–90,000 lb./in.²; tensile strength 90,000–105,000 lb./in.²; elongation 17–22% in 2 inches; reduction of area 45–50%. These values are about the same as those quoted by Jennings. Strauss also stated that the maximum hardness in a welded plate 2 5/16 inches thick containing 0.25 C, 1 Cr, 0.2 V was 223 Vickers Brinell in the heat-affected zone, which was sorbitic. Base metal was 175 Brinell.

Atomic hydrogen weld-metal containing 0.28 C. 0.70 Mn, 1.08 Cr, 0.17 V (filler rod contained 0.50 C, 0.67 Mn, 0.98 Cr, 0.18 V) was tested by Weinman,[68] Table 13. The rotating bend fatigue limit of all specimens was 25,000 lb./in.²

Rose[69] found that butt welds in 1/2-inch plate (0.23–0.30 C) made with a bare electrode containing 0.475 C, 0.63 Mn, 0.17 Si, 0.90 Cr, 0.27 V had a yield strength of 26,000 lb./in.², tensile strength 56,000 lb./in.² with fracture in base metal. Vincent[70] used a similar bare electrode (0.51 C, 0.60 Mn, 0.19 Si, 0.89 Cr, 0.15 V) but without notable success (no details). Depositing coated Cr–V electrodes containing 0.47 C, 0.71 Mn, 0.26 Si, 0.91 Cr, 0.20 V on Cr-Ni steel and machining the deposits to cones 1 inch high, Hibbard[71] found that the weld-metal contained 0.16 C, 0.58 Mn, 0.20 Si, 0.86 Cr, 0.19 V and were 250 Brinell. After 5 heavy blows in the AERA test the metal was compressed to 36.5% of its original height and was 298 Brinell. Owing to the small size of the cones, the metal was deposited under exceptionally hot conditions. Perhaps for this reason the results were not encouraging. Eckman[6] reports a tensile strength of 75,000–76,000 lb./in.² in a flash-welded steel containing 0.17–0.22 C, 0.60–0.75 Mn, 0.15 Si, 0.65–0.80 Cr, 0.12–0.16 V. The tensile strength unwelded was 80,000 lb./in.²

General Observations

Jennings[21] regards the arc welding of Cr-V steels of S. A. E. 6115 type with shielded arc electrodes as a simple matter. Preheating to 150–260° C. (300–500° F.) is often beneficial for heavy sections. Since Cr-V steels are sometimes subject to temper brittleness, the cooling rate after stress annealing, for example at 620° C. (1150° F.), should be controlled accordingly. It appears that Cr-V steels for welding purposes offer little difficulty from the standpoint of temper brittleness. According to the Vanadium Corporation,[72] S. A. E. 6115, 6120 and 6125 have been welded with heavily fluxed electrodes for pressure vessels. The vessels are usually stress relieved, but some are full annealed. S. A. E. 6145 is widely used for gas and electric surfacing of worn railway rails, the gas welding rods being bare or copper coated and the electrodes being heavily fluxed. The deposited metal is 300 Brinell which rises to 440 Brinell as a result of cold working in service.

Cr-V steel is a good filler rod for oxyacetylene welding, in Kinzel and Crafts'[38] opinion but its use for aircraft

Table 13—Mechanical Properties of Atomic Hydrogen Welds Made with a Cr-V Steel Filler Rod. Weinman[68]

	Composition of Weld Cr	Composition of Weld V	Proportional Limit, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 2 In.	Reduction of Area, %	Rockwell B Hardness Weld	Rockwell B Hardness Base Metal
All-Weld-Metal	1.08	0.17	69,000	111,450	7.3	30.3	...	...
Single-V weld in steel containing 0.35 C, 2 1/4 Ni, 0.40 Mo	1.02	0.16	39,500	101,300	6.5	33.5	111 1/2	108
Single-V weld in steel containing 0.09 C, 0.50 Mn	0.86	0.09	21,500	64,900	22.0	61.5	103	69

Table 14—Average Tensile Strength of Butt-Welded Cr-Mo Sheet. Cornelius[79]

Thickness of Sheet, Inch	No.	Diameter, Inch	Welding Rod C	Si	Mn	Cr	Mo	Coating	Type of Joint	Tensile Strength, Lb./In. Welded	Welded and Heat Treated
0.04	1	0.06	0.04	0.01	..	..	..	Dipped	Butt, unscarfed	92,500	131,000
0.04	2	0.06	0.12	0.06	0.40	..	..	Heavy covered	Butt, unscarfed	92,000	103,000
0.04	3	0.06	0.1	0.05	1.0	..	..	Heavy covered	Butt, unscarfed	90,500	133,000
0.04	4	0.08	0.1	0.20	0.33	0.82	0.21	Dipped	Butt, unscarfed	95,000	135,000*
0.04	5	0.06	0.08	0.07	0.59	..	..	Oxyacetylene rod	Butt, unscarfed	91,000	132,000
0.04	6	0.06	0.18	0.26	0.57	0.74	0.16	Oxyacetylene rod	Butt, unscarfed	92,000	138,000*
0.08	4	..	..	..	..	..	..	...	70° V butt	91,000	133,000*
0.08	7	0.10	about 0.1	about 0.5	about 1.0	..	..	Heavy covered	70° V butt	94,000	127,000
0.08	7	..	..	..	..	..	..	...	Unscarfed butt, 0.04 inch gap	92,000*	98,500
0.12	8	1/8	about 0.1	about 0.5	about 1.0	..	..	Heavy covered	80° V butt	94,000 to 95,000	115,000 to 121,000*

* = Fracture occurred in base metal remote from weld.

tubing has declined because it softens rapidly on tempering and is not so intensely air hardening as Cr-Mo.

Petinot[73] observed too that S. A. E. 6125–6130 has excellent welding qualities as fuselage tubing; vanadium was believed to restrain grain growth in weld and fusion zone (no details). Corneil's[63] experience with S. A. E. 6120, quoted in the preceding section on Mechanical Properties, showed that the lowest possible current gave the best results, especially if the welding was done without interruption and the deposit was peened.

One difficulty with Cr-V electrodes has been the recovery of vanadium, although the results quoted in the preceding section suggest that the difficulty is easily overcome with coatings. With light coatings, all the vanadium is oxidized, Harris[18] found. The average loss determined by Strauss (quoted by Harris[18]) from ten different Cr-V electrodes with three different coatings was 0.045% V, the maximum being 0.11% V. Presumably the electrodes contained 0.1–0.2 V (no details). In atomic hydrogen welding, Weinman[68] found practically no loss of Cr or V with a rod containing, 0.98 Cr, 0.18 V. Green[74] stated that only 64% (electrode negative) or 59% (electrode negative) of a bare electrode containing 0.49 C, 0.70 Mn, 0.99 Cr, 0.16 V was deposited as weld-metal on a 1 1/4-inch stud. The rest was lost by spatter or vaporization. The deposit efficiency was low in comparison with other alloy steels.

Hollow aircraft propellers of S. A. E. 6130 with two atomic hydrogen welded seams are described by Foley.[75] The welding is followed at once by annealing at 925° C. and heat treatment. It appears that cracking was a difficulty. A Russian writer[76] describes a gas-welded column for ammonia synthesis which was 30 inches diameter, 0.28 to 0.63 inch thick made of steel containing 0.17–0.22 C, 1–1.2 Cr, 0.15–0.18 V. The welded columns were heated to 760–820° C. after welding, peened, reheated to 820° C., cooled to 620° C. in 15 min. and air cooled. Churchward[77] (1920) built up the bearing surface of a crankshaft containing 0.28 C, 0.68 Mn, 0.12 Si, 0.95 Cr, 0.17 V with an electrode 0.148 inch diameter containing 0.40 C, 1.0 Mn, 0.10 Si. After being air quenched from 900° C., oil quenched from 840° C., and drawn at 550° C. there was no indication of the heat-affected zone in the microstructure 0.39 inch from the fusion line and only a slight effect 0.04 inch from the fusion line.

WELDING CHROMIUM-MOLYBDENUM STEELS

Of all the low-alloy chromium steels that have been studied from the standpoint of welding, the chromium-molybdenum steel of S. A. E. 4130 or X4130 type has received the most attention. The chromium-molybdenum steels have been used to a great extent in aircraft construction where, as pointed out by Johnson,[78] their air-hardening capacity combined with high strength and good ductility have been most valuable. Their freedom from temper brittleness, noted by Harris[18] has also been an advantage in heat-treated assemblies. The following sections summarize what has been published on the strength developed by welded joints, the metallurgical characteristics of the steels in welding, and the peculiarities of the steel which must be familiar to the welder of the chromium-molybdenum steels. Resistance welding is discussed in a separate section. The fatigue strength of welded tubing was summarized in the review of literature on The Fatigue Strength of Welded Joints.

Mechanical Properties

In view of the fact that over thirty investigations of the mechanical properties of welded chromium-molybdenum steels have been made, they are summarized in chronological order. The reviewers are relieved, in this way, of the responsibility of giving preference to any one of a number of equally authoritative investigations and have been able to indicate as clearly as possible the numerous details each of which are crucial to the results of a given investigation and could not have been indicated conveniently in a tabulated summary.

1938. Cornelius.[79]—The average tensile strength of unmachined metal arc and oxyacetylene welds in sheet 0.04, 0.08 and 0.12 inch thick containing 0.26 C, 0.3 Si, 0.6 Mn, 1.0 Cr, 0.2 Mo, 0.01 S, 0.015 P is given in Table 14. The arc welds were made with a rectifier. The composition of the metal deposited by the electrodes is given in Table 14; only the composition of the oxyacetylene filler rod before welding is shown. There were only slight quantities of non-metallic inclusions in the arc welds. The heat-treated joints were oil quenched from 850° C. and drawn 1/2 hr. at 600° C. Fracture occurred at the junction of the sheet and weld except in the three instances designated with an asterisk.

Electrode 4 and oxyacetylene welding rod 6 produced the best welds in the thinnest sheet. An electrode of type 4 was not available for the thicker sheets.

Pulsating tension fatigue tests on metal arc and oxyacetylene welded specimens 0.08 inch thick, 1 3/4 inches wide revealed a fatigue limit for both of: lower tensile stress = 14,200 lb./in.,[2] upper tensile stress = 31,300 to 32,700 lb./in.[2]

1938. Bollenrath and Cornelius.[80]—A determination of the stress-cycle curve was made for unmachined, oxyacetylene butt-welded seamless tubes, Table 15, 0.04-inch

Table 15—Static Tensile Properties of Tubes Used by Bollenrath and Cornelius[80]

Tube No.	C	Si	Mn	P	S	Cr	Mo	Yield Strength, 0.2% Offset, Lb./In.²	Tensile Strength, Lb./In.² Unwelded	Tensile Strength, Lb./In.² Welded	Elongation, % Unwelded
1*	0.23	0.19	0.59	0.020	0.005	1.02	0.24	92,500	105,000	.....	.....
2†	0.25	0.32	0.67	0.009	0.005	1.04	0.22	89,500	134,000 to 138,000	.....	14 to 16
3†	0.25	0.32	0.66	0.009	0.005	1.04	0.21	85,000	126,000 to 128,000	.....	15 to 21
4‡	0.25	0.32	0.65	0.009	0.005	1.01	0.27	130,000	137,000	.....	9.8
5	0.26	0.23	0.63	0.008	0.01	0.99	0.24	91,000 to 94,000* 122,000‡	97,000 to 101,000* 131,000 to 132,000‡	88,000 to 90,000* 127,000 to 132,000‡	13 to 18* 9 to 10‡
Filler rod	0.18	0.26	0.57	0.019	0.006	0.74	0.16	diameter = 0.06 inch.			

* = As drawn tube (annealed and straightened).
† = Normalized tube (15 min. at 840° C., air cooled).
‡ = Heat treated tube (15 min. at 840° C., oil quenched, then ½ hr. at 600° C.).
The free length of the specimens was 4 inches. Only tubes 1 and 5 were welded.

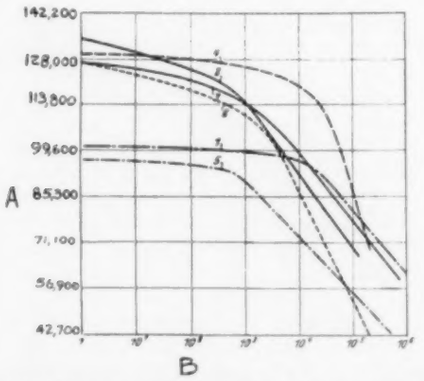

Fig. 2(*a*)—Lowest Positions of the Stress-Cycle Curves for Unwelded and Butt-Welded Cr-Mo Steel Tubes 1.10 Inches o.d., 0.04-Inch Wall After Different Heat Treatments

A = Upper stress, lb./in.²
B = Number of cycles
Lower stress = 16,800 lb./in.²
1. Tube No. 1, annealed then cold drawn
2. Tube No. 2, normalized
3. Tube No. 3, normalized
4. Tube No. 4, heat treated
5. Tube No. 5, welded
6. Tube No. 1, welded, then heat treated. Bollenrath and Cornelius[80]

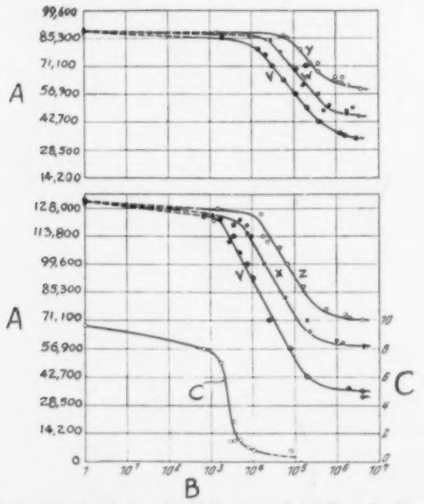

Fig. 2(*b*)—Stress-Cycle Curves for Pulsating Axial Tensile Stress of Butt-Welded Cr-Mo Steel Tubes 0.79 Inch o.d., 0.04-Inch Wall, As-Welded and Heat Treated

Upper diagram—as-welded, not heat treated
Lower diagram—heat treated
A = Upper stress, lb./in.²
B = Number of cycles
C = Elongation, % in 4 inches at fracture
v = Lower stress = 14,200 lb./in.²
w = Lower stress = 28,500 lb./in.²
x = Lower stress = 35,600 lb./in.²
y = Lower stress = 42,700 lb./in.²
z = Lower stress = 57,000 lb./in.²
Bollenrath and Cornelius[80]

wall thickness, 0.79 and 1.10 inches o.d. on a Losenhausen pulsator at 1000 cycles/min. The tubes showed no sensitivity to cracking in the Focke-Wulf clamp test, and required no straightening after welding.

The stress-cycle curves in Fig. 2 (*a*) and (*b*) were made at a lower tensile stress of 16,800 lb./in.² Welding places the curve in a more unfavorable position, and heat treating raises the stress values up to 10^5 cycles, but steepens the slope of the curve. Up to 1000 cycles, repeated stress has little effect on the strength. As the lower tensile stress is raised, the stress-cycle curve is displaced to higher strengths for a given number of cycles beyond 1000. Between 1000 and 10,000 cycles the type of fracture of the untreated welds changed from a ductile fracture ½ inch outside the weld to a brittle fracture originating at the junction of weld with tube. Fracture of the heat-treated tubes always occurred at the weld junction because heat treatment removed the soft zone and homogenized the structure. For the latter reason the stress-cycle results for the heat-treated tubes showed less scatter. The endurance limit was attained at 10^6 cycles.

The fatigue diagrams for all ranges of stress from alternating tension-compression to pulsating tension of all types are shown in Fig. 3. The heat-treated tube is

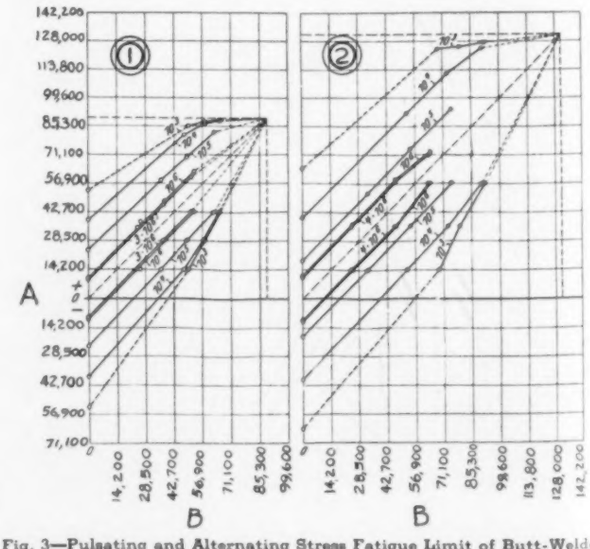

Fig. 3—Pulsating and Alternating Stress Fatigue Limit of Butt-Welded Cr-Mo Steel Tubes 1.10 Inches o.d., 0.04-Inch Wall, As-Welded and Heat Treated as a Function of Number of Cycles

A = Upper and lower stress, lb./in.²
B = Mean stress, lb./in.²
1 = As-welded, not heat treated
2 = Welded and heat treated
Bollenrath and Cornelius[80]

superior to the as-welded in the region of high mean tensile stress and at 10^3 to 10^4 cycles. At 10^5 cycles the heat-treated tube is superior only with a mean tensile stress above 64,000 lb./in.^{2} With tensile stress pulsating from zero to a maximum the endurance limit was 19,200 lb./in.^{2} for the as-welded tube, 21,400 lb./in.^{2} for the heat treated. The corresponding values for alternating axial stress ($\pm$ S max.) are $\pm$ 9300 and $\pm$ 10,700 lb./in.,[3]

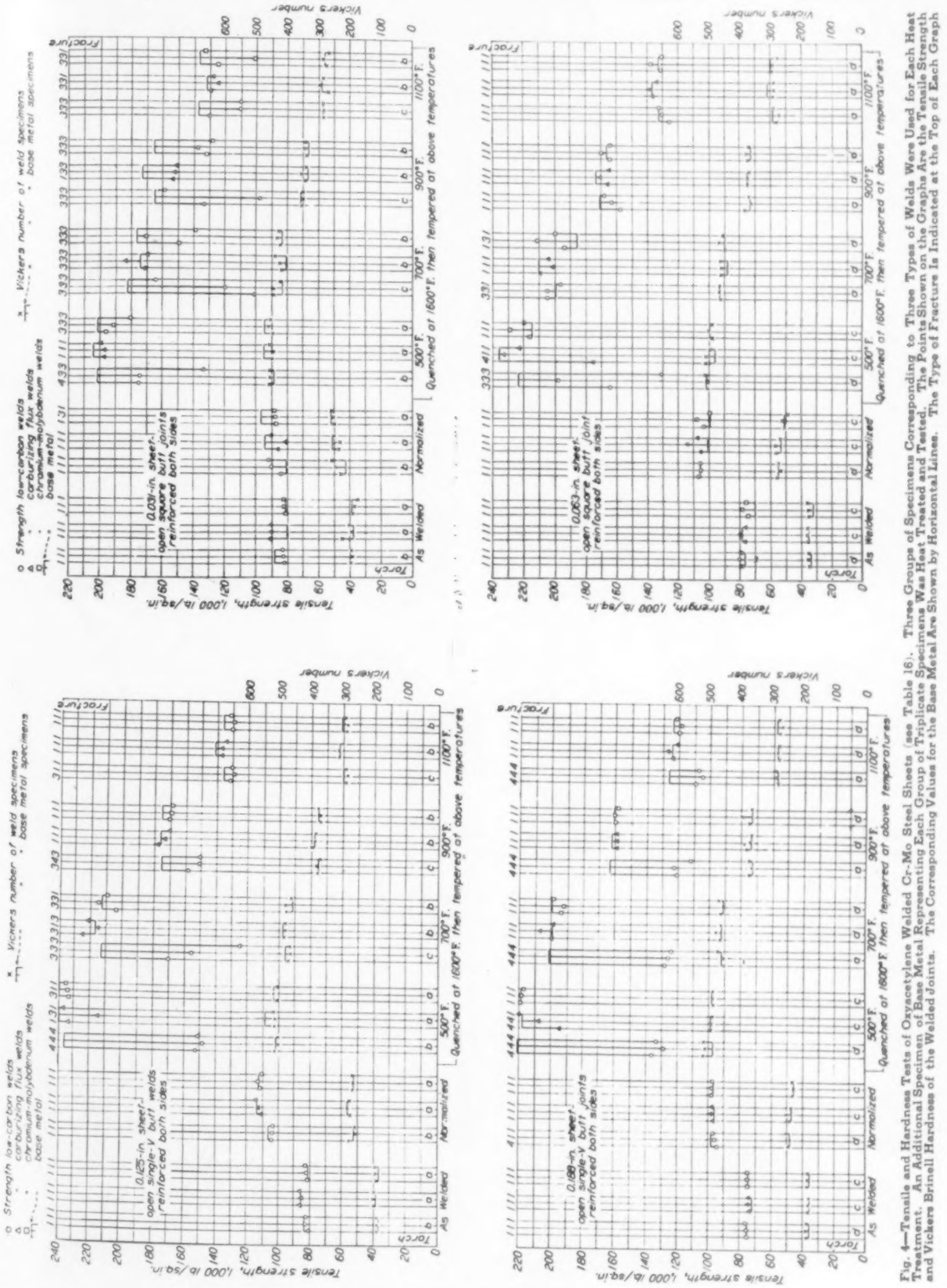

Fig. 4—Tensile and Hardness Tests of Oxyacetylene Welded Cr-Mo Steel Sheets (see Table 16). Three Groups of Specimens Corresponding to Three Types of Welds Were Used for Each Heat Treatment. An Additional Specimen of Base Metal Representing Each Group of Triplicate Specimens Was Heat Treated and Tested. The Points Shown on the Graphs Are the Tensile Strength and Vickers Brinell Hardness of the Welded Joints. The Corresponding Values for the Base Metal Are Shown by Horizontal Lines. The Type of Fracture Is Indicated at the Top of Each Graph

1 = Fracture in base metal outside heat-affected zone
2 = Fracture in soft zone
3 = Fracture at edge of weld
4 = Fracture in weld. Bruegeman[11]

respectively. The reversed bend fatigue limit was higher, namely 18,500 lb./in.^{2} as-welded, 27,700 to 29,200 lb./in.^{2} after heat treatment (see this section, 1937, Bollenrath and Cornelius[83]). Heat treatment has more effect in raising the reversed bend endurance limit than the reversed axial stress endurance limit.

1937. Brueggeman.[81]—The tubes listed in Table 16 had many oxidized and decarburized seams. Four different oxyacetylene welding outfits were used with equal success. Two methods of oxyacetylene welding were used. A neutral flame (forward welding) was used with the mild steel and Cr-Mo rods. The carburizing flux method was used with the appropriate rod, not with the low-carbon steel rod. The luminous feather was 2 to $2^1/_2$ times the length of the inner cone. The method utilizes the carburized film caused by the adsorption of carbon by the molten steel when heated in carburizing gases. The film has a low melting point and acts as a flux preventing oxidation of the metal ahead of the torch. Since the base metal is not heated to the melting point, the torch must be manipulated to confine the melted puddle to as small an area as possible. Forward welding was used for the tubes thicker than 0.030-inch wall.

Table 16—Materials Used by Brueggeman[81]

Material	C	Mn	P	S	Si	Cr	Mo
Tubes 1 inch o.d., 0.035-inch wall	0.27	0.43	0.01	0.012	..	0.89	0.20
Tubes $1^1/_2$ inch o.d., 0.020-inch wall	0.27	0.57	0.01	0.012	..	0.94	0.20
Tubes $1^1/_2$ inch o.d., 0.058-inch wall	0.34	0.54	0.022	0.011	..	1.09	0.19
Ditto (another lot)	0.34	0.50	0.023	0.010	..	1.08	0.19
Sheet 0.031 inch thick	0.30	0.42	0.015	0.008	..	0.89	0.18
Sheet 0.063 inch thick	0.32	0.41	0.016	0.004	..	0.90	0.20
Welding rod, low-carbon steel, $^1/_{16}$, $^3/_{32}$, $^1/_8$ inch diameter	0.02	0.02	...	...	..	..	..
Welding rod, carburizing flux type	0.17	1.02	0.02	0.024	0.38	..	..
Welding rod, Cr-Mo type	0.41	0.90	0.02	0.006	0.58	1.13	0.20

Although there was no significant difference between the welding speeds in the two processes, and there was no cracking in the sheet welds, only the carburizing flux method could be relied upon for crack-free welds in the thin-walled tubes. Welds made with the low-carbon steel rod (neutral flame) in tubing had many intercrystalline cracks partly filled with oxide and about $^1/_2$ inch long. The cracks occurred in base metal $^1/_{32}$ inch away from, and parallel to, the weld. These cracks occurred despite (1) local torch preheating to a red heat, (2) removing all mill scale near the weld with emery cloth, (3) heating one side of the joint by torch while welding the other side, (4) preventing excessive penetration, (5) using small tips, (6) using backward instead of forward welding, or (7) sawing out a portion of a continuous tube covered by an intersecting tube. All heat treatment was done in a reducing atmosphere. The tube joints were welded in a jig which does not appear to have offered any restraint to welding distortion. It should be emphasized that cracks occurred only in tubing $1^1/_2$ inches o.d., 0.020-inch wall.

Butt Joints in Sheets (see Fig. 4).—The welds were made in the direction of rolling and were reinforced on both sides. A 90° V joint was used in the thicker sheets (0.125 and 0.188 inch thick); thinner sheets were not scarved. The tensile specimens were $^1/_2$ inch wide, parallel portion $4^1/_2$ inches long. The welds were not machined. The reinforcement varied from 83–92% of sheet thickness in 0.188 inch sheet to 143–235% of sheet thickness in 0.031-inch sheet.

In general, the full strength of base metal was realized in the as-welded and normalized joints in all four thicknesses. Fractures occurred in base metal outside the heat-affected zone. Of the quenched and tempered joints, those made by the carburizing flux method in the 0.031-inch sheet were best. In the other thicknesses the strength of the carburizing flux welds was slightly greater and more uniform than those made with the Cr-Mo rod, except at the 260° C. (500° F.) temper. Most of the heat-treated welds in 0.031-inch sheet fractured at the edge of the weld. Otherwise, fractures occurred in base metal outside the heat-affected zone. None of the welded sheets failed in the zone in which the welding heat created a local annealing effect. Furthermore, none

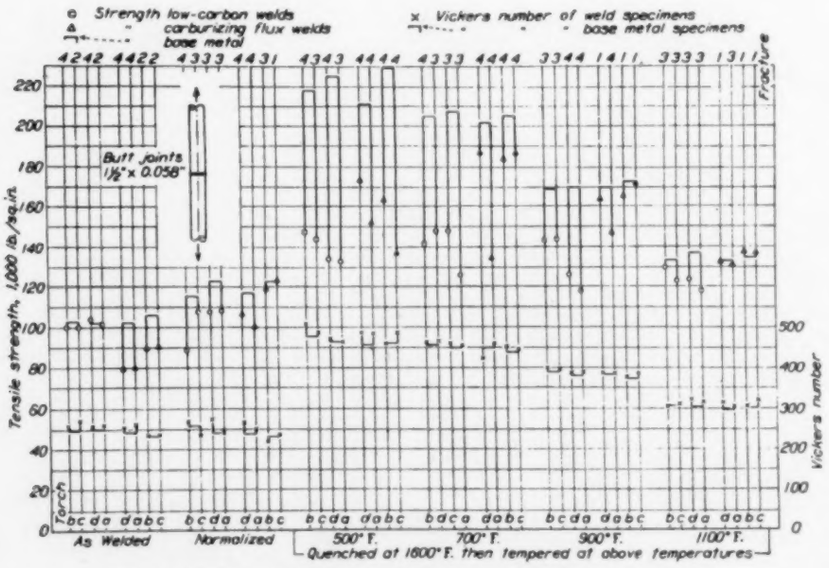
o Strength low-carbon welds
Δ " carburizing flux welds
" base metal
x Vickers number of weld specimens
" " base metal specimens
4242 4422 4333 4431 4343 4444 4333 4444 3344 1411 3333 1311
Fracture
Butt joints 1½"x 0.058"
Tensile strength, 1,000 lb./sq.in.
Vickers number
Torch
bcda dabc bcda dabc bcda dabc baca dabc bcda dabc bcda dabc
As Welded
Normalized
500° F.
700° F.
900° F.
1100° F.
Quenched at 1600° F. then tempered at above temperatures

Fig. 5—Tensile and Vickers Hardness Tests of Oxyacetylene Welded Cr-Mo Steel Tubes (see Table 16). Brueggeman[81]

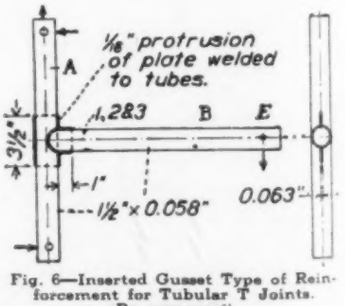

Fig. 6—Inserted Gusset Type of Reinforcement for Tubular T Joints. Brueggeman[81]

Table 17—Reversed Bend Fatigue Strength of Welded Cr-Mo Tubing. Cornelius and Bollenrath[83]

			Unwelded			Welded		
Method of Welding	Type of Joint	Heat Treatment	Tensile Strength, Lb./In.²	Elongation % in 5 Diam.	Reversed Bend Fatigue Limit, Lb./In.²	Tensile Strength, Lb./In.²	Reversed Bend Fatigue Limit, Lb./In.²	100 × Fatigue Limit/ Tensile Strength
...	Unwelded	none	104,000	9.5	41,300	....	....	..
Oxyacetylene	butt	none	104,000	9.5	....	98,000	18,500	18.9
Atomic hydrogen	butt	none	....	..	....	....	24,200	..
Oxyacetylene	⩔	none	....	..	....	....	20,000	..
Oxyacetylene	butt	A	119,000	12.9	....	118,000	24,200	20.5
Oxyacetylene	butt	B	167,000	5.8	....	161,000	22,500	14.1
Oxyacetylene	butt	C	151,000	7.4	....	148,000	29,300	19.7
Oxyacetylene	butt	D	130,000	8.6	....	128,000	28,300	22.0
Atomic hydrogen	butt	D	....	..	....	....	22,800 (!)	..
Oxyacetylene	butt	E	120,000	11.0	....	121,000	28,500	23.6

A = Air cooled from 840° C.
B = Oil quenched from 840° C; tempered ½ hr. at 500° C.
C = " " " " " " " " 550° C.
D = " " " " " " " " 600° C.
E = " " " " " " " " 650° C.
The temperature was maintained 15 minutes at 840° C. in all tests.

of the Cr-Mo joints and only 3 carburizing flux joints (one in 0.063-inch sheet and two in 0.188-inch sheet, all tempered at 500° F.) fractured in the welds; there was marked reduction of area in these exceptional fractures.

Butt Joints in Tubes (*see Fig. 5*).—There was more scatter in the strength of tubular butt joints than welded sheet or unwelded tubing. In the 1½ x 0.058 inch tubes the carburizing flux welds were stronger than the low-carbon welds in the quenched and tempered condition. Fracture in the carburizing flux welds occurred either in the weld or remote therefrom, seldom at the edge. More of the low-carbon welds failed at the edge than in the weld. Tempering at any temperature had little effect on the quenched welds. In other words the joints tempered at 260° C. (500° F.) had tensile strengths of 130,000–170,000 lb./in.²; those tempered at 600° C. (1100° F.) had 120,000 to 140,000 lb./in.², but the tensile strength of unwelded tubes dropped from 220,000 to 130,000 lb./in.² in the same range.

In the thin-walled tubes (1½ x 0.020 inch not heat treated) all the low-carbon steel welds failed at welding cracks. Of the carburizing flux welds, two failed in the weld, one at the edge, and four in the annealed zone. Those failing in the weld had low strength (55,000 and 68,000 lb./in.²); the others developed 92,000–110,000 lb./in.² Possibly the reinforcement was insufficient on some of the joints.

Intersecting joints had the lowest strength of any heat-treated joints. Practically all except the as-welded joints failed at the edge of the weld on account of the abrupt change in cross section and accompanying stress concentration. The carburizing flux welds were slightly stronger than those made with the same rod using neutral flame technique.

It was found that the inserted gusset type of reinforcement for T and lattice joints, Fig. 6, was better than any other from the standpoints of strength, weight, welding speed and cracks. The inserted gusset type of joint comprises a T shaped sheet inserted in slots in the tube; the edge of the sheet protrudes slightly. Detailed cross bend and cantilever tests on reinforced joints of several types showed that all joints made with thin walled tubing buckled before developing 0.1-inch set. Lattice joints made with Cr-Mo tubing had higher efficiencies than similar joints in plain-carbon steel tubing (0.24–0.28 C, 0.5 Mn). Cr-Mo steel therefore retains its reputation for good welding characteristics.

Brueggeman's tests show that butt-welded Cr-Mo sheet and tubing in as-welded or normalized condition has about the same strength as unheat-treated base metal, provided the weld is free from cracks and the tubing is not too thin. Oil quenched base metal has 20 to 30% greater strength than the welded joint if fracture occurs at the weld. The difference between unwelded and welded decreases as the tempering temperature is increased from 260 to 600° C. (500 to 1100° F.). The inserted gusset is valuable for strengthening welded lattice joints in Cr-Mo tubing provided the wall thickness is sufficient to prevent local collapse of the tubing under load. The carburizing flame technique was successful in avoiding cracks in thin walled tubing (1½ inches o.d., 0.020-inch wall) where many other remedies failed.

1937. M. L. Smith.[82]—Test welds made with heavy covered "chrome-nickel" electrodes (no details) in S. A. E. X4130 tubing 0.065-inch wall had tensile strengths up to 140,000 lb./in.² after heat treatment. Load tests on a completed arc welded landing gear were successful.

1937. Cornelius and Bollenrath.[83]—The reversed bend fatigue strength of oxyacetylene and atomic hydrogen welded seamless tubing, Table 17, is favorably affected by heat treatment. The tubing contained 0.23 C, 0.19 Si, 0.59 Mn, 0.020 P, 0.005 S, 1.02 Cr, 0.24 Mo and was 1.10 inches o.d., 0.04-inch wall. It was not sensitive to welding cracks as revealed by Focke-Wulf clamp tests. (In the Focke-Wulf test, two sheets are held rigidly while being welded.) The filler rod contained 0.18 C, 0.57 Mn, 0.26 Si, 0.019 P, 0.006 S, 0.74 Cr, 0.16 Mo. The lattice joint consisted of two tubes 0.59 inch diam., 0.04-inch wall welded diagonally to the middle portions of a 1.10-inch tube. The unwelded heat-treated tubes exceeded the capacity (about 42,700 lb./in.²) of the plane cantilever reversed bend fatigue testing machine, of which no details are supplied. Specimens were not straightened before being tested. The atomic hydrogen welds (heat treatment D) were not made according to best practice.

The microstructure of the welds had an important bearing on the results. The surface of the unwelded tubes was found to be decarburized to a depth of 0.002–0.003 inch. The pearlite was uniformly distributed in tubes annealed ¼ hr. at 840° C. except for a layer 0.004 inch deep at the surface, which contained low carbon but still was amenable to heat treatment. Only in the as-received or normalized tubes could any decrease in fatigue

strength be attributed to decarburization. Welds made by either process were coarse grained and had no free ferrite. After being normalized or oil quenched and drawn at 550° C. weld and base metal had the same grain size and structure, the well-known "martensitic" structure.

All tensile fractures in the welded specimens occurred in the heat-affected zone. All fatigue fractures occurred at the junction of the weld with base metal. Very erratic results were obtained from the as-welded tubes. Two specimens withstood 10 million cycles at 24,800 and 25,600 lb./in.², respectively, whereas two other specimens broke at lower loads. Since the structure of the as-welded atomic hydrogen tube, which failed only after 13 million cycles at 25,600 lb./in.², was identical with the oxyacetylene weld, the higher fatigue strength of the former may be attributed to the smaller overheated zone. Heat treatment decreased the scatter probably owing to increase in tensile strength and improvement in structure. At low draws (500° C.) the notch effect predominated. At higher drawing temperatures (550-650° C.) the structural improvement predominated.

Investigations on the pulsating tension fatigue limit of butt-welded Cr-Mo aircraft sheet by E. Schiedt and K. Schraivogel[84] showed that specimens 1.18 inches wide (no details) free from cracks as revealed by X-ray and magnaflux inspection withstood 5 million cycles at an upper tensile stress of 31,300 to 34,200 lb./in.² (lower tensile stress = 5700 lb./in.²). Under similar conditions, specimens with cracks 0.04 inch deep extending over 50% of the width of the specimen could withstand 5 million cycles only with an upper tensile stress of 8500 to 10,000 lb./in.² Yet static tensile failure in the cracked specimens occurred in the heat-affected zone remote from the cracks. Porosity and large inclusions not on the surface were not so dangerous as cracks.

1937. Jennings.[21]—Typical properties of welds in S. A. E. X4130 (0.30 C, 0.45 Mn, 0.90 Cr, 0.17 Mo) made with shielded arc carbon-molybdenum electrodes (no details) are shown in Table 18.

Table 18—Mechanical Properties of Arc-Welded S. A. E. X4130. Jennings[21]

Material	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation % in 2 In.	Reduction of Area, %
Unwelded	60,000–70,000	100,000–110,000	20–30	50–60
As-welded	60,000	80,000	28	...
As-welded and annealed 650° C. (1200° F.)	55,000	75,000	34	...

1937. Soudeur-Coupeur.[85]—In explaining details of aircraft construction with oxyacetylene welded Cr-Mo steel (0.20–0.25 C, 0.40 Mn, 0.15 Si, 0.003 S, 0.003 P, 0.80–1.10 Cr, 0.25 Mo), it is stated that welded sheet 0.02 to 0.10 inch thick has a tensile strength of at least 86,000 lb./in.² with at least 180° bend and 10% elongation (no details). A welded fitting was severely distorted in an accident but the welds did not break.

1937. Knerr.[86]—Butt-welded S. A. E. X4130 (low-carbon steel welding rod) has a tensile strength of 80,000 lb./in.² as-welded, 140,000 lb./in.² after quench and draw.

1936. Johnson.[87]—The tensile strength and rotating bend fatigue limit of oxyacetylene butt-welded tubing 1 inch o.d., 1/16-inch wall in S. A. E. X4130 are shown in Table 19 (no details).

Table 19—Tensile and Fatigue Strengths of Oxyacetylene Welded S. A. E. X4130 Tubing. Johnson[87]

Heat Treatment After Welding	Filler Rod	Tensile Strength, Joint, Lb./In.²	Rotating Bend Fatigue Limit, Lb./In.² Base Metal	Rotating Bend Fatigue Limit, Lb./In.² Welded Joint
None	Low-carbon steel	95,000	41,000	16,000
Heated 30 min. at 510° C. (950° F.)	Low-carbon steel	95,000	41,000	18,000
Heated 30 min. at 900° C. (1650° F.)	Low-carbon steel	90,000	....	16,000
None	Cr-Mo steel	95,000	41,000	18,000

1936. Zeyen.[88]—Oxyacetylene welds in plain carbon steels, Table 20, were made with a filler rod containing about 1% Cr, 0.2 Mo. Detailed results are given of parallel section tensile and bend tests on butt welds 0.24 and 0.47-inch plate, of fillet weld tension tests, and of notch impact, fatigue and hardness tests. The last three tests involved the weld-metal almost exclusively The notch impact specimen was the standard German round notch type, notch diameter = 0.08 inch, notch depth = 0.12 inch, cross section 0.47 x 0.47 inch outside notch. The welds were made in 0.47-inch plate and the notch was in weld-metal. The reversed bend fatigue specimen was unmachined, 0.24-inch plate, 0.79 inch wide at reduced section, 10 million cycles criterion. The Brinell hardness was measured with a Firth machine.

Table 20—Mechanical Properties of Oxyacetylene Welds in Plain Carbon Steels Made with a Rod Containing 1 Cr, 0.2 Mo. Zeyen[88]

Base Metal C	Si	Mn	Notch Impact Value, Mkg./Cm.²	Reversed Bend Fatigue Limit, Lb./In.²	Brinell Hardness in Weld 1/2 In. Thick 0.04 Inch from Top of Weld	0.24 Inch from Top of Weld
0.11	0.12	0.47	9.8	22,800	167	140
0.17	0.31	0.55	7.8	not determined	170	158
0.30	0.23	0.56	6.4	28,500	174	170
0.38	0.29	0.64	6.2	25,600	177	174
0.56	0.32	0.63	5.1	24,200	187	187
0.60	0.33	0.63	4.6	not determined	184	191
0.68	0.35	0.69	2.0	24,200	187	207

1936. De Ganahl.[89]—Oxyacetylene welded Cr-Mo tubing (0.30 C, 1.0 Cr, 0.25 Mo) has a tensile strength of 80,000 lb./in.,² which is increased to 200,000 lb./in.² by heat treatment.

1936. Lincoln Handbook.[50]—The effect of heat treatment on the tensile strength of shielded arc and carbon arc welds in S. A. E. 4130 is shown in Table 21. The heat treatment consisted of annealing the weld at 900–950° C. (1650–1750° F.), oil quenching from 850–900° C. (1550–1650° F.) and drawing at 510° C. (950° F). The carbon arc process was slower than the shielded arc.

Table 21—Effect of Heat Treatment on Arc-Welded S. A. E. 4130. Lincoln Handbook[50]

Welding Process	Tensile Strength, Lb./In.² As-Welded	Tensile Strength, Lb./In.² Heat Treated
Shielded Arc	60,000–80,000	125,000–150,000
Carbon Arc	60,000–70,000	125,000–160,000

1936. Lubovsky.[9]—A brief discussion is given of tensile and corrosion (H_2SO_4) tests on coated electrode welds (25–55 amps.) in steel 0.04–0.06 inch thick containing 0.25–0.35 C, 0.4–0.6 Mn, 0.8–1.2 Cr, 0.15–0.25 Mo.

Table 22—Tensile and Bend Properties of Oxyacetylene Welded Cr-Mo Steel. Sutton[90]

Carbon Content %	Proportional Limit, Lb./In.² Welded			Tensile Strength, Lb./In.² Welded			Elongation, % in 2 In Welded			No. of Back-and-Forth Bends to Fracture Welded		
	Unwelded	Cr-Mo Rod[1]	Iron Wire	Unwelded	Cr-Mo Rod	Iron Wire	Unwelded	Cr-Mo Rod	Iron Wire	Unwelded	Cr-Mo Rod	Iron Wire
0.27	....	....	....	104,000	93,000	....	21.0	...	....	closed	1	...
0.29	19,700–24,000	....	....	118,000–126,000	103,000–108,000	103,000	9.0–15.0	...	....	closed	closed	closed
0.30	18,800	....	....	129,000–139,000	112,000	100,000*	13.5–15.0	...	....	½ to 1	½	1
0.31	....	....	....	124,000	110,000*	....	7.0	...	....	½	½	..
0.32	....	38,800	38,500	139,000	115,000–116,000	116,000 or 79,000*–100,000*	14.5	5.0	1.0–2.0	¾	..	1½
0.33	....	....	....	128,000	49,000*	....	7.5	...	....	⅛	..	..

(1) = Rod of base metal.
* = Failed at weld.

1935. Sutton.[90]—Tensile and bend properties of unwelded and oxyacetylene welded steel containing 0.27 to 0.33 C, 0.4–0.5 Mn, 1 Cr, 0.19–0.27 Mo are given in Table 22. Iron wire or wire of the same composition as base metal was used. The ductility of the weld depended closely on the carbon content of the steel.

1935. Zeyen.[91]—Table 23 shows that heat treatment of oxyacetylene welds in Cr-Mo sheet (0.26 C, 0.28 Si, 0.40 Mn, 0.95 Cr, 0.15 Mo, 0.043 inch thick) made with a Cr-Mo rod has a good effect on the mechanical properties.

Table 23—Effect of Heat Treatment on Tensile Properties of Oxyacetylene Welded Cr-Mo Steel. Zeyen[91]

Specimen	Heat Treatment	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in $11.3\sqrt{A}$
Unwelded	None	64,000	91,500	18
Welded	None	.....	90,000	..
Unwelded	Hardened	134,000	233,000	5
Welded	Hardened	.....	208,000	..
Unwelded	Hardened and tempered	114,000	124,000	8
Welded	Hardened and tempered	.....	120,000	..

A = Cross-sectional area.

1935. Calbiani.[92]—Tensile tests on unmachined oxyacetylene welds made with a low-carbon steel rod in tubes containing 0.25–0.35 C, 0.40–0.60 Mn, 0.04 S max., 0.04 P max., 0.8–1.10 Cr, 0.15–0.25 Mo, 1.18 inch o.d., 0.047-inch wall are summarized in Table 24. Tests were also

Table 24—Effect of Heat Treatment on Oxyacetylene Welded Cr-Mo Tubing. Calbiani[92]

Treatment	Tensile Strength, Lb./In.²	Elongation, % in $11.3\sqrt{A}$
As-received	110,000	14.5
As-welded	97,000	6.7
Welded and normalized	103,000	9.5
Unwelded, Annealed	77,000	21.3
Annealed, Then Welded	79,000	13.9
Annealed, Welded, Then Normalized	105,000	12.7

A = Cross-sectional area in sq. mm.

made on tubes 0.59 inch o.d., 0.032-inch wall and 1.26 inch o.d., 0.10-inch wall. All fractures in the 0.59-inch tubes occurred in the weld, except the normalized specimens, which broke 2½ inches from the weld. All fractures in the 1.18-inch tubing occurred ¾ inch from the weld, with the exception of the normalized specimens which broke 2 inches from the weld. The largest tubes broke ¾ inch from the weld regardless of heat treatment. Although normalizing (no details) in the furnace was beneficial, local torch heating of the weld to the critical point followed by air cooling had little effect. A detailed study of the distribution of elongation along the welded tubes was made, but did not result in an explanation of the location of fracture in the different specimens. The structure of the heat-affected zone appeared to be martensitic.

1935. Ward.[93]—The failure of unmachined oxyacetylene butt welds in S. A. E. 4130 occurs in the softened zone of base metal some distance from the weld, unless there is misalignment. Welded tubes have 60% ± 5% of the strength of unwelded tubes. Heat treatment (normalize 930° C., water quench from 900° C., temper 480° C.) after welding increases the strength to 90% of unwelded. The ductility of the welded joints varies between 60 and 71% of unwelded. The endurance limit of welded tubing may be taken as 25% of the static tensile strength (no details).

1935. Doussin.[94]—The rotating bend fatigue limit of oxyacetylene welded Cr-Mo aircraft tubing was determined (see review of literature on Fatigue Strength of Welded Joints).

1935. British Aeronautical Research Committee.[95]—The fatigue strength of as-welded Cr-Mo tubing is ± 24,600 lb./in.² (no details).

1935. Hoffmann.[96]—If a Cr-Mo steel rod (0.25–0.35 C, 0.15–0.35 Si, 0.4–0.6 Mn, 0.03 S, 0.025 P, 0.8–1.0 Cr, 0.15–0.25 Mo) depositing weld-metal containing 0.12 C, 0.04 Si, 0.2 Mn, 0.03 S, 0.025 P, 0.4–0.6 Cr, 0.1–0.17 Mo is used for oxyacetylene welding Cr-Mo steel aircraft tubing, the welded joint has a yield strength of 71,000 to 76,000 lb./in.², tensile strength of 90,000 to 102,000 lb./in.² (no details).

1934. Müller.[97]—The tensile strength of oxyacetylene butt-welded Cr-Mo tubes (1 Cr, 0.25 Mo) 0.040-inch wall was 86,000 lb./in.², 90° bend angle when the weld had a sorbitic (ferrite-pearlite) structure (250 Brinell) and 91,000 lb./in.² 40° bend when the structure was coarse martensite (350 Brinell). The bend test consisted of bending a sheet 0.78 inch wide fillet welded radially to the tube. The hardness ⅜ to ½ inch from the weld was 180–190 Brinell.

1934. Royal Aircraft Establishment.[98]—Low-pressure acetylene butt welds made with an iron rod in as-drawn and blued steel 1 inch o.d., 16 gage, containing 0.33 C, 1.2 Cr, 0.2 Mo were tested, Table 25, after being oil quenched from 900° C. and drawn at 560° C.

Table 25—Tensile and Fatigue Strength of Oxyacetylene Welded Cr-Mo Tubing. Royal Aircraft Establishment[98]

Specimen	0.1% Proof Stress, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 2 In.	Four Point Alternating Bend Fatigue Limit (10 Million Cycles), Lb./In.²
Unwelded but heat treated	139,000–146,000	149,000	24–25	±33,400
Welded and heat treated	.....	121,000–132,000	Fracture at weld	±22,600

1933. Streb and Kemper.[99]—Oxyacetylene butt welds in mild steel (0.63 inch thick, minimum tensile strength 53,000 lb./in.²) and low-alloy steel (0.47 inch thick, 0.20 C, 0.67 Si, 1.04 Mn, 0.53 Cu) were made with a rod containing 0.30 C, 0.52 Mn, 0.31 Si, 0.89 Cr, 0.21 Mo, 0.12 Cu. Machined reduced section tensile specimens (1 inch wide at reduced section) of welded mild steel had a tensile strength of 71,000 lb./in.² with only 6% bend elongation. The tensile impact value was fair. In the low-alloy steel the tensile impact value was very good (40% higher than welded mild steel); the tensile strength was 92,000 lb./in.², but the bend elongation was only 8%. Fracture occurred in the weld in both steels. Welds in 0.4 C steel (no details) made with the Cr-Mo rod had a tensile strength of 111,000 lb./in.² It was concluded that the welds made with the Cr-Mo rod had high strength but low ductility.

1932. Rechtlich.[100]—The tensile strength of oxyacetylene welded tubing containing 0.25–0.35 C, 1.1 Cr, 0.2 Mo is 93,000 to 107,000 lb./in.² Heat treatment raises the tensile strength to 155,000–170,000 lb./in.², if a Cr-Mo steel rod is used.

1931. Zeyen.[101]—Tensile and bend tests on oxyacetylene butt welds in four steels in sheet form, 0.047 inch thick are summarized in Tables 26 to 29. The same welder was used in all tests. He employed four filler rods: 1. strips of the same composition as base metal; 2. chromium steel welding rod containing about 2% Cr; 3. soft iron welding rod; 4. mild steel welding rod. The results of the mild steel rod were nearly the same as the soft iron rods and have not been reproduced in Tables 26 to 29. The weld in the tensile specimens was ground flush with base metal. Had the weld not been ground flush failure would have occurred in the soft zone, it was believed. The bend test was made in a vise so that the unmachined weld was bent over a sheet of the same thickness as base metal. All results are averages of at least two tests.

Zeyen concluded that steels 2 and 3 were best because they had the best tensile properties when the sheet was

Table 26—Mechanical Properties of Oxyacetylene Welded Sheet (No. 1) Containing 0.15 C, 0.17 Si, 0.30 Mn, 0.010 P, 0.010 S, 0.088 Cr, 0.57 Mo. Zeyen[101]

Condition of Sheet			Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in $11.3\sqrt{A}$	Bend Angle at First Crack, Degrees
Before Welding	After Welding	Filler Rod				
As-rolled	Unwelded	Unwelded	121,000	139,000	11.1	180
Heat treated	Unwelded	Unwelded	53,000	70,000	25.3	(4 1/2 bends)
As-rolled	Not heat treated	Base metal	....	99,000	1.3	180
As-rolled	Heat treated	Base metal	67,000	80,000	14.2*	>180
Heat treated	Not heat treated	Base metal	63,000	79,000	9.2*	180
Heat treated	Heat treated	Base metal	67,000	80,000	14.3*	>180
As-rolled	Not heat treated	2% Cr	....	99,000	..	160
As-rolled	Heat treated	2% Cr	64,000	76,000	10.3	>180
Heat treated	Not heat treated	2% Cr	58,500	75,000	8.7*	180
Heat treated	Heat treated	2% Cr	58,500	73,000	10.2	>180
As-rolled	Not heat treated	Soft iron	....	74,000	..	180
As-rolled	Heat treated	Soft iron	64,000	76,000	8.3	>180
Heat treated	Not heat treated	Soft iron	60,000	70,000	12.0*	180
Heat treated	Heat treated	Soft iron	63,000	72,000	13.0	>180

Heat Treatment: 10 min. at 900° C., air cooled, then 1 hr. at 700° C., air cooled.
* = Fractured outside the weld.
A = Cross-sectional area.

Table 27—Mechanical Properties of Oxyacetylene Welded Sheet (No. 2) Containing 0.17 C, 0.22 Si, 0.31 Mn, 0.012 P, 0.010 S, 1.48 Cr, 0.51 Mo. Zeyen[101]

Condition of Sheet			Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in $11.3\sqrt{A}$	Bend Angle at First Crack, Degrees
Before Welding	After Welding	Filler Rod				
As-rolled	Unwelded	Unwelded	142,000	164,000	11.9	180
Heat treated	Unwelded	Unwelded	80,000	93,000	19.0	(4 1/2 bends)
As-rolled	Not heat treated	Base metal	....	126,000	...	180
As-rolled	Heat treated	Base metal	81,000	92,000	6.9	180
Heat treated	Not heat treated	Base metal	78,000	91,000	11.9*	170
Heat treated	Heat treated	Base metal	74,000	87,000	12.6*	>180
As-rolled	Not heat treated	2% Cr	....	136,000	...	170
As-rolled	Heat treated	2% Cr	81,000	93,000	8.7	>180
Heat treated	Not heat treated	2% Cr	78,000	94,000	9.2*	180
Heat treated	Heat treated	2% Cr	71,000	82,000	10.5	>180
As-rolled	Not heat treated	Soft iron	....	119,000	...	175
As-rolled	Heat treated	Soft iron	74,000	86,000	9.0	>180
Heat treated	Not heat treated	Soft iron	78,000	89,000	10.4*	170
Heat treated	Heat treated	Soft iron	76,000	83,000	6.7	>180

Heat Treatment: 10 min. at 900° C., air cooled, then 1 hr. at 700° C., air cooled.
* = Fractured outside the weld.
A = Cross-sectional area.

Table 28—**Mechanical Properties of Oxyacetylene Welded Sheet (No. 3) Containing 0.20 C, 0.19 Si, 0.18 Mn, 0.020 P, 0.010 S, 1.30 Cr, 0.30 Mo. Zeyen**[101]

Condition of Sheet			Yield Strength,	Tensile Strength,	Elongation,	Bend Angle at First Crack,
Before Welding	After Welding	Filler Rod	Lb./In.^{2}	Lb./In.^{2}	% in $11.3\sqrt{A}$	Degrees
As-rolled	Unwelded	Unwelded	142,000	164,000	10.7	96
Heat treated	Unwelded	Unwelded	104,000	120,000	11.2	(2½ bends)
As-rolled	Not heat treated	Base metal	....	134,000	...	170
As-rolled	Heat treated	Base metal	90,000	106,000	10.8*	180
Heat treated	Not heat treated	Base metal	111,000	125,000	4.3*	170
Heat treated	Heat treated	Base metal	97,000	108,000	6.1	>180
As-rolled	Not heat treated	2% Cr	....	134,000	...	170
As-rolled	Heat treated	2% Cr	110,000	120,000	3.7	>180
Heat treated	Not heat treated	2% Cr	99,000	114,000	5.0*	170
Heat treated	Heat treated	2% Cr	90,000	103,000	9.2	180
As-rolled	Not heat treated	Soft iron	....	101,000	...	150
As-rolled	Heat treated	Soft iron	97,000	102,000	4.0	>180
Heat treated	Not heat treated	Soft iron	90,000	102,000	6.3	160
Heat treated	Heat treated	Soft iron	83,000	89,000	3.7	180

Heat Treatment: 10 min. at 920° C., oil quenched, then 1 hr. at 640° C., air cooled.
* = Fractured outside the weld.
A = Cross-sectional area.

Table 29—**Mechanical Properties of Oxyacetylene Welded Sheet (No. 4) Containing 0.34 C, 0.20 Si, 0.63 Mn, 0.010 P, 0.010 S, 1.03 Cr, 0.28 Mo. Zeyen**[101]

Condition of Sheet			Yield Strength,	Tensile Strength,	Elongation,	Bend Angle at First Crack,
Before Welding	After Welding	Filler Rod	Lb./In.^{2}	Lb./In.^{2}	% in $11.3\sqrt{A}$	Degrees
As-rolled	Unwelded	Unwelded	142,000	170,000	9.2	95
Heat treated	Unwelded	Unwelded	110,000	124,000	14.9	(2½ bends)
As-rolled	Not heat treated	Base metal	....	116,000	4.9*	170
As-rolled	Not heat treated	Base metal	108,000	120,000	4.5	180
Heat treated	Not heat treated	Base metal	113,000	136,000	6.7*	155
Heat treated	Heat treated	Base metal	100,000	115,000	7.5	180
As-rolled	Not heat treated	2% Cr	104,000	116,000	3.1*	170
As-rolled	Heat treated	2% Cr	108,000	113,000	2.0	180
Heat treated	Not heat treated	2% Cr	96,000	117,000	9.0*	175
Heat treated	Heat treated	2% Cr	101,000	118,000	6.8	180
As-rolled	Not heat treated	Soft iron	....	108,000	2.5	170
As-rolled	Heat treated	Soft iron	94,000	104,000	4.5	>180
Heat treated	Not heat treated	Soft iron	....	100,000	...	165
Heat treated	Heat treated	Soft iron	94,000	100,000	4.7	180

Heat Treatment: 10 minutes at 920° C., oil quenched, then 1 hr. at 640° C., air cooled.
* = Fractured outside the weld.
A = Cross-sectional area.

heat treated but the joint was not. The optimum composition was 0.20–0.25 C, 1.3–1.5 Cr (Mo content not stated). Steel 1 was too weak; steel 4 was too brittle and the scatter was too large. Zeyen did not consider the question whether, had the weld not been ground flush, the soft zone, supposing it to be the controlling factor, was stronger in steels 2 and 3 than in steel 1. His hardness tests, which are discussed in the next section, showed that, as a matter of fact, the soft zone was softer in steel 1 than in steels 2 and 3. In common with other investigators, Zeyen found that the welds made with the alloy steel rods had finer grain structure, approaching the fineness of base metal, than the plain carbon steel rods.

1931. Baumgärtel.[102]—Rotating bend Fatigue tests of oxyacetylene welded tubes 1 inch o.d., 0.06- or 0.12-inch wall are summarized in Table 30. The low-carbon steel rod provided easy welding but the Cr-Mo steel rod formed a gassy pool and a brown slag containing Fe, Mn, Cr and Mo. In view of these difficulties the scarf angle was increased from 60 to 80° and the reinforcement was made 30% higher than with the low-carbon steel rod. Fatigue failure always occurred in the zone of Widmannstätten structure a short distance from the weld, unless there were obvious defects.

1930. Whittemore and Brueggeman.[103]—Tensile tests were made of a large number of types of welded joints in tubing containing 0.30–0.31 C, 0.46–0.49 Mn, 0.13–0.17

Table 30—**Rotating Bend Fatigue Strength of Oxyacetylene Welded Cr-Mo Tubing. Baumgärtel**[102]

	Composition											Fatigue Strength, Lb./In.^{2}	
Specimen	C	Si	Mn	P	S	Cu	Cr	Mo	Yield Strength, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation, %	0.06-Inch Wall	0.12-Inch Wall
Unwelded tubing	0.33–0.34	0.14–0.15	0.57–0.58	0.02	0.02	0.03	0.95–0.99	0.25–0.27	92,000	110,000	12	33,900 to 34,200	
Low-carbon steel rod	0.07	0.009	0.46	0.032	0.026	..	...	...	....	.....	..	21,500	19,100
Cr-Mo steel rod	0.34	0.15	0.55	0.022	0.02	0.03	0.96	0.27	....	102,000	..	20,000	21,600

Si, 0.96–0.99 Cr, 0.22–0.24 Mo, 0.09–0.14 Ni, 0.01–0.03 V with a rod ($^1/_{16}$, $^3/_{32}$ and $^1/_8$ inch diameter) containing 0.02 C, 0.02 Mn. The tubes were of three sizes: 2 x 0.065 inch, 1 $^1/_8$ x 0.049 inch and $^3/_4$ x 0.028 inch. Right-hand and left-hand oxyacetylene welding were used. There was no difference among the four types of torches that were used.

Of 15 butt joints in tension all but one failed $^1/_2$ inch from the weld where the hardness was 150–180 Brinell. The weld was 170 Brinell; the base metal was 225–275 Brinell. The single exception failed in the weld. The tensile strengths were 80,000 to 100,000 lb./in.^{2} (efficiencies = 80 to 93%). Stress-strain curves were recorded in which one leg of a 1-inch Huggenberger extensometer was either on the weld or remote from the weld. The proportional limit at the weld was 20,000 to 40,000 lb./in.^{2}; remote from the weld it was 60,000 to 90,000 lb./in.^{2}

Compression tests (15 L/r) of butt-welded tubes resulted in failure by folding $^1/_2$ inch from the weld. The compressive strength was 70,000 to 95,000 lb./in.^{2}, efficiencies were 80 to 92%.

In T joints it was better to secure increased strength by using larger tubes than by adding plates or straps. (The inserted gusset plate described by Brueggeman[81] in 1937 was not used.) The efficiencies of unreinforced T joints was 55 to 77%. U-shaped straps raised the efficiency to 87%.

1930. Johnson.[104]—Tensile tests on butt and T welds in aircrafts sheet containing 0.25–0.35 C, 0.40–0.60 Mn, 0.040 P max., 0.045 S max., 0.8–1.10 Cr, 0.15–0.25 Mo made with a low-carbon steel rod or a rod of the same analysis as base metal but containing 0.15 C are listed in Table 31. Welding lowered the tensile strength less than 15%. If the joint must be heat treated, Johnson found, in common with other investigators, that the Cr-Mo steel rod must be used.

Table 31—Tensile Strength of T and Butt Welds in Cr-Mo Steel. Johnson[104]

Plate Thickness, Inch	Tensile Strength, Lb./In.^{2} Before Welding	After Welding
0.250	92,000	91,000
0.125	98,000	87,000
0.039	105,000	90,000

1930. Downes.[105]—Unheat-treated, unmachined butt welds in S. A. E. X 4130 made with low-carbon or Cr-Mo rod always fail $^1/_2$ inch from the weld at 85,000 to 105,000 lb./in.^{2} tensile strength, 3 to 7% elongation in 2 inches.

1929. Kindelberger.[106]—Butt welds in Cr-Mo aircraft tubing have a tensile strength of 85,000 to 98,000 lb./in.^{2}, based on the cross-sectional area of the tube. Fish-mouth welds (usually 30° but sometimes 45°) fail at 98,000 to 111,000 lb./in.^{2} The design strength of welds is 80% of base metal in the normalized condition: 60,000 lb./in.^{2} yield strength; 95,000 lb./in.^{2} tensile strength; 5 to 10% elongation, depending on thickness. Failures always occur $^1/_2$ inch from the weld in the annealed area. Some welded Douglas fuselages have had over 2200 flying hours without trouble.

1929. Hackett.[4]—Oxyacetylene butt welds in steel containing 0.3 C, 1 Cr, 0.2 Mo always fractured in tension about $^1/_2$ inch from the weld. The tensile strength was the same as base metal, 103,000 lb./in.^{2}, but the elongation was only 3% in 2 inches at the fracture instead of 14% in the unwelded steel. In an alternating stress test at 1140 r.p.m. (no details) welded Cr-Mo tubes failed after 250,000 cycles at 35,800 lb./in.^{2} whereas welded 1.5% Mn tubing failed at 113,000 cycles.

1928. Daniels.[107]—Oxyacetylene butt welds in tubing containing 0.32 C, 0.56 Mn, 0.93 Cr, 0.23 Mo (tensile strength 100,000 lb./in.^{2}, yield strength 70,000 lb./in.^{2}, elongation 12% in 2 inches) made with a rod containing 0.28 C, 0.01 Mn, 1.14 Cr, 0.95 Mo had the same yield strength and tensile strength as base metal, but the elongation was only 4% in 2 inches across the break, which occurred $^1/_2$ inch from the weld. Welded Cr-Mo tubing water quenched from 880° C. (1625° F.) and drawn at 430–680° C. (800–1250° F.) had a tensile strength of 155,000 to 110,000 lb./in.^{2}, elongation 4 to 17% in 2 inches.

1928. Johnson.[108]—The yield strength of welds in Cr-Mo aircraft tubing is 72,000 lb./in.^{2}, tensile strength 96,000 lb./in.^{2}, elongation 7% in 2 inches.

1927. R. R. Moore.[109]—The rotating bend fatigue limit of unmachined oxyacetylene butt welds in plain carbon steel tubes 1 inch o.d., $^1/_{16}$-inch wall, made with a rod containing 0.28 C, 0.61 Mn, 1.14 Cr, 0.95 Mo was only 8000 lb./in.^{2}, although the tensile strength was 59,400 lb./in.^{2} with failure 1 inch from the weld.

1926. Hird.[66]—Unmachined butt arc welds made with a thin coated electrode containing 0.06 C max., 0.15 Mn max., 0.04 P max., 0.04 S max., 0.08 Si $^1/_{16}$ to $^3/_{32}$ inch diameter in 17 and 20 gage tubing $^3/_4$ to 1$^1/_2$ inches diameter containing 0.25–0.35 C, 0.40–0.60 Mn, 0.04 P max., 0.045 S max., 0.80–1.10 Cr, 0.15–0.25 Mo had efficiencies of 85 to 103% with bead on and 83 to 99% with the bead machined off in tension tests. Fracture occurred in the fusion zone in the unmachined specimens, and in the weld in the machined specimens. Unmachined T joints failed in the fusion zone with efficiencies of 96 to 107%. Annealing (heating 10 minutes at 870–900° C., cooling to 600° C. during 3 hr. in furnace, followed by air cooling) lowered the efficiency of unmachined butt welds to 60%. The arc welds were as good as gas welds (see section on General Observations).

1925. Sisco and Boulton.[75]—Tensile tests were made on unmachined oxyacetylene butt welds in the tubing shown in Table 32. All as-welded tubes failed 1$^1/_2$ to 3 inches from the weld, the strength and ductility being governed by the composition of the weaker of the tubes in the combination joints. Both filler rods produced the same results. Heat treatment increased the strength, and, if the drawing temperature was 540 or 680° C., the ductility was also increased. Excellent results were obtained by drawing at 540° C., after water quenching from 885° C. The mechanical properties of welded joints so heat treated closely approached the mechanical properties of unwelded base metal. The unwelded base metal referred to in Table 32 contained 0.34 C, 0.52 Mn, 0.94 Cr, 0.31 Mo, and was not the same as the tubing used for welding. The absence of softened zones in the heat-treated tubes was reflected in the location of fracture, which was erratic. As in other investigations the tensile strength of the welded joint more nearly approached base metal as the drawing temperature was increased. Sisco and Boulton concluded that heat treatment of welded tubing is desirable unless warpage is serious. If warpage is a problem, simple normalizing may be good (no details).

From the standpoint of uniformity of structure, the low-carbon rod was best with low-carbon tubes, the Cr-Mo rod was best with Cr-Mo tubes, and both rods were equivalent with medium-carbon tubes. The Cr-Mo weld-metal had finer grain structure than the low carbon.

Table 32—Tensile Tests on Oxyacetylene Welded Aircraft Tubing. Sisco and Boulton[65]

Specimen	Heat Treatment	Filler Rod	Proportional Limit, Lb./In.²‡	Tensile Strength, Lb./In.²	Elongation % in 2 In.	Elongation % in 8 In.	Location of Fracture	Character of Fracture	Number of Tests
Cr-Mo tube to Cr-Mo tube	None	Plain Carbon	51,520 to 52,490*	98,990 to 103,050	2.5 to 4.5	0.62 to 1.25	1½ inches from weld	Square	6
Cr-Mo tube to Cr-Mo tube	None	Cr-Mo	41,990 to 44,990†	100,050 to 103,200	3.0 to 5.0	0.87 to 1.37	1½ inches from weld	Square	6
Cr-Mo tube to medium-carbon steel tube	None	Plain Carbon	36,600 to 37,400	63,800 to 66,500	28 to 31	10.8 to 11.1	2½ to 3 inches from weld in plain carbon tube	Square and diagonal	2
Cr-Mo tube to medium-carbon steel tube	None	Cr-Mo	34,650 to 37,600	63,200 to 68,200	27 to 30.5	10.0 to 11.1	2½ to 3 inches from weld in plain carbon tube	Diagonal	2
Cr-Mo tube to low-carbon steel tube	None	Plain Carbon	21,400 to 24,500	48,650 to 49,800	47 to 47.5	19.5 to 20.4	3 inches from weld in plain carbon tube	Jagged	2
Cr-Mo tube to low-carbon steel tube	None	Cr-Mo	25,640 to 26,700	50,200 to 51,300	44.5 to 46	16.9 to 18.6	2½ to 3 inches from weld in plain carbon tube	Jagged	2
Cr-Mo tube to Cr-Mo tube	Water quenched 885° C. (1625° F.); drawn at 430° C. (800° F.)	Cr-Mo	117,000 to 122,600	151,500 to 161,700	1.0 to 4.0	0.62 to 2.75	2—at weld 1—1" from weld 1—2½" from weld	Square at weld; Others spiral	4
Cr-Mo tube to Cr-Mo tube	Water quenched 885° C. (1625° F.); drawn at 540° C. (1000° F.)	Cr-Mo	94,400 to 100,400	135,800 to 146,200	7.5 to 11.0	3.1 to 5.4	Remote from weld	Jagged or spiral	4
Cr-Mo tube to Cr-Mo tube	Water quenched 885° C. (1625° F.); drawn at 680° C. (1250° F.)	Cr-Mo	64,900 to 66,380	105,000 to 111,500	14.0 to 17.5	7.75 to 8.5	1½ to 3½ inches from weld	Jagged	4
Cr-Mo tube	Water quenched 885° C. (1625° F.); drawn at 430° C. (800° F.)	Unwelded	150,000	180,000	8				
Cr-Mo tube	Water quenched 885° C. (1625° F.); drawn at 540° C. (1250° F.)	Unwelded	125,000	145,000	12				

* Yield strength = 69,000 lb./in.²
† Yield strength = 73,000 lb./in.²
‡ Berry strain gage sensitive to 0.0002 inch.

Composition of Materials

	C	Mn	S	Cr	Mo
Cr-Mo tubing, 1 inch o.d., 0.036-inch wall, cold drawn, seamless	0.32	0.56	...	0.93	0.23
Medium-carbon tubing, 1 inch o.d., 0.036-inch wall, cold drawn, seamless	0.31	0.45	0.038	...	...
Low-carbon tubing, 1 inch o.d., 0.036-inch wall, cold drawn, seamless	0.18	0.49	0.030	...	...
Low-carbon filler rod, 1/16 inch diameter, copper coated	0.03	0.48	...	...	...
Cr-Mo filler rod, 1/16 inch diameter, uncoated	0.28	0.61	...	1.14	0.93

The phosphorous content was below 0.04% in all material.
Quenching water was at 16° C. (60° F.); air cooled from drawing temperature.

Hardness

Hardness surveys of welded joints in Cr-Mo aircraft steel have been made in an effort to explain the location of fracture. As shown in the preceding section reinforced butt welds in aircraft tubing usually fail at a definite point, namely, the heat-affected zone, unless there are major defects in the weld or the joint has been heat treated.

In their research on Cr-Mo tubing discussed in the preceding section, Whittemore and Brueggeman[103] found that weld-metal was 170 Vickers, base metal was 225 to 275, and the heat-affected zone reached a maximum of 300. At 1/2 inch from the weld the hardness was only 150 to 180. The soft zone was narrow, perhaps 1/4 inch wide, and was sandwiched between the hardened portion of the heat-affected zone and the relatively hard tubing. The soft zone, therefore, had no opportunity to elongate in tension.

Similar results had been obtained by Sisco and Boulton[65] in 1925, Table 33. Their materials have been described in the preceding section, Table 32. The soft zone was more pronounced in the heavy walled tubing than in the light walled and was between 1/2 and 7/8 inch from the weld. However, fracture in the tensile test of the as-welded Cr-Mo tubing welded with plain carbon or Cr-Mo filler rod occurred 1 1/2 inches from the weld. The elongation was only 5% (max.) in 2 inches, that is 0.10 inch across the fracture. The tubes did not fail in the softest zone in the tensile tests. Perhaps the soft zone exerted some effect, but the weld reinforcement probably had an effect, too. In the as-welded tubes the maximum hardness was usually very close to the weld.

There was no soft zone in the heat-treated tubes. The maximum hardness of about 500 Brinell in the as-quenched joint was reduced to about 270 Brinell maximum by drawing at 540° C.

Table 33—Rockwell Hardness of Oxyacetylene Welded Cr-Mo Tubing. Sisco and Boulton[65]

	Cr-Mo Tubing 90° V Butt Welds 0.125 Inch Wall		Cr-Mo Tubing Unscarfed Butt Welds, 0.036-Inch Wall			
Tubing						
Filler Rod	Plain Carbon	Cr-Mo	Plain Carbon	Cr-Mo	Cr-Mo	Cr-Mo
Heat Treatment	None	None	None	None	Water quenched 885° C. (1625° F.)	Water quenched 885° C. (1625° F.); drawn at 540° C. (1000° F.)
Rockwell Hardness						
Center of weld	No result	B 94	B 66	B 106	C 46	C 18
1/4 in. from weld	B 85–90	B 75–85	B 102	B 101	C 45–48	C 25–27
3/4 in. from weld	B 95–98	B 89–95	B 87–88	B 92–94	C 47	C 20–25
1 3/8 in. from weld	....	....	B 96–97	B 97–100	C 47	C 19–26
Maximum hardness	B 102	B 104	B 102	B 103	C 50	C 27
Location	1 1/4 inches from weld	1/8 inch from weld	1/4–3/8 inch from weld	1/8 inch from weld	1 inch from weld	1/8 inch from weld
Minimum hardness	B 80	B 75	B 87	B 86	C 44	C 18
Location	Soft zone 1/2 to 5/8 inch from weld	Soft zone 5/8 to 7/8 inch from weld	Soft zone 5/8 to 7/8 inch from weld	Soft zone 1/2 to 3/4 inch from weld	1/8 inch from weld	1 1/2 inches from weld

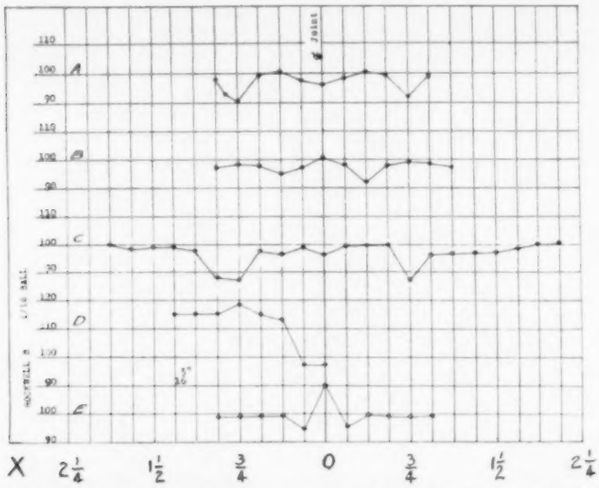

Fig. 7—Rockwell B Hardness Along Oxyacetylene Welded S. A. E. X4130, 1 Inch o.d., 0.065-Inch Wall

A = Oxyacetylene weld
B = D. C. metal arc
C = Oxyacetylene weld heated to 1625° F., air-cooled
D = Oxyacetylene weld heated to 1625° F., oil-quenched, drawn 900° F.
E = Flash weld
X = Distance from center of weld, inches. Johnson[67]

Johnson's tests, Fig. 7, showed that the soft zone is farther from the weld as the heat input of the welding process increases. The soft zone is $^3/_4$ inch from the oxyacetylene weld, $^3/_8$ inch from the arc weld, and about $^3/_{16}$ inch from the flash weld. For some reason air cooling from 885° C. (1625° F.) accentuates the soft zone of the oxyacetylene welded joint.

On thicker sheet, Brueggeman[81] found that normalizing eradicated the soft zone of oxyacetylene welded joints, Fig. 8. The hardness of base metal varied with heat treatment, Figs. 4 and 5. The hardness was measured with a Vickers machine, 10 kg. load for 0.031-inch sheet, 30 kg. load for thicker sheet; if the hardness was over 250 Brinell a 50 kg. load was used. Impressions were spaced $^1/_{32}$ to $^1/_4$ inch apart.

In the as-welded condition, Cr-Mo weld-metal was 350–450 Vickers; carburizing flux weld-metal was 150–200; low-carbon weld-metal was 150–200; unaffected base metal was 180–200. The maximum hardness in

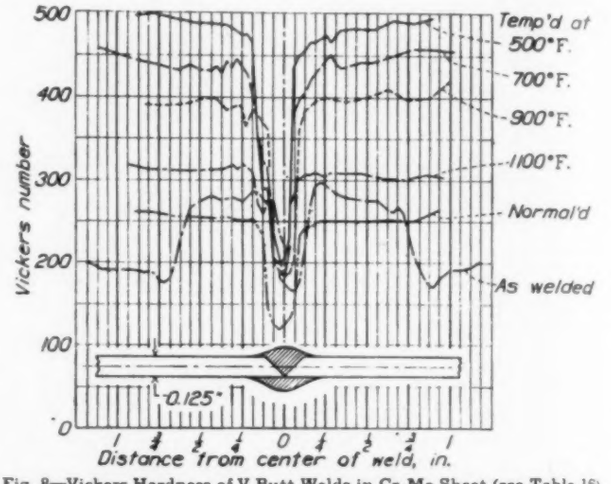

Fig. 8—Vickers Hardness of V Butt Welds in Cr-Mo Sheet (see Table 16). The Welds Have Been Given Different Heat Treatments. Quenching Was in Oil After $^3/_4$ Hr. at 1600° F. Tempering Time Was 1 Hr. Followed by Air Cooling. Normalizing Was 1 Hr. at 1600° F., Air Cooled. Brueggeman[81]

Table 34—Crack Sensitivity of Cr-Mo Steel Sheets Used by Bardenheuer and Bottenberg[110]

Melt No.	Ingot No.	Kind of Furnace	Melting Procedure	Composition of Finished Melt, % C	Si	Mn	Cr	Mo	P	S	Total Gas Content of Steel, Cm.³ per 100 Gm.	Crack Sensitivity in Oxyacetylene Welding Heated 1/2 Hr. at 650° C. As Cold Rolled	Before Welding
1	1	Acid coreless induction	No boil, low temperature	0.28	0.17	0.45	1.01	0.37	0.025	0.017	16.4	0	0
1	4	Acid coreless induction	No boil, low temperature	0.36	0.12	0.36	1.01	0.37	0.024	0.018	n.d.	1	24
2	1	Acid coreless induction	No boil, low temperature	0.29	0.42	0.45	1.03	0.39	0.013	0.017	n.d.	15	7
2	5	Acid coreless induction	No boil, low temperature	0.27	0.41	0.43	1.03	0.36	0.048	0.023	14.4	61	54
3	1	Acid coreless induction	No boil, low temperature	0.30	0.21	0.55	1.10	0.31	0.012	0.013	14.3	0	0
3	4	Acid coreless induction	No boil, low temperature	0.30	0.25	0.56	1.07	0.28	0.014	0.065	12.3	52	69
4	4	Acid coreless induction	Slight boil, low temperature	0.30	0.39	0.57	1.02	0.32	0.022	0.010	14.1*	10	12
5	2	Basic arc	Active boil, high temperature	0.41	0.31	0.63	1.22	0.37	0.010	0.008	8.8	0	0
8	4	Acid coreless induction	High temperature	0.26	0.25	0.42	1.09	0.33	0.042	0.009	n.d.	0	0
8	6	Acid coreless induction	High temperature	0.27	0.30	0.41	1.07	0.34	0.102	0.010	13.8	47	36
14	1	Acid coreless induction	**	0.26	0.24	0.60	1.12	0.27	0.033	0.038	15.7	17	22
14	2	Acid coreless induction	**	0.26	0.28	0.58	1.10	0.29	0.033	0.039	13.4	5	3
14	3	Acid coreless induction	**	0.25	0.36	0.52	1.10	0.29	0.033	0.039	8.7	0	0

n.d. = Not determined
* = 0.23 Al
** = Melt held 1 hr. at low temperature. Ingot No. 1 was cast after alloy was added. Temperature was raised to slow boil. Ingot No. 2 cast after second hour. Temperature raised to active boil. Ingot No. 3 cast after 1 1/2 hour.

This table does not do justice to the thorough tabulation of their melts given by Bardenheuer and Bottenberg. Translations of their complete Table will be sent to any interested reader upon request.

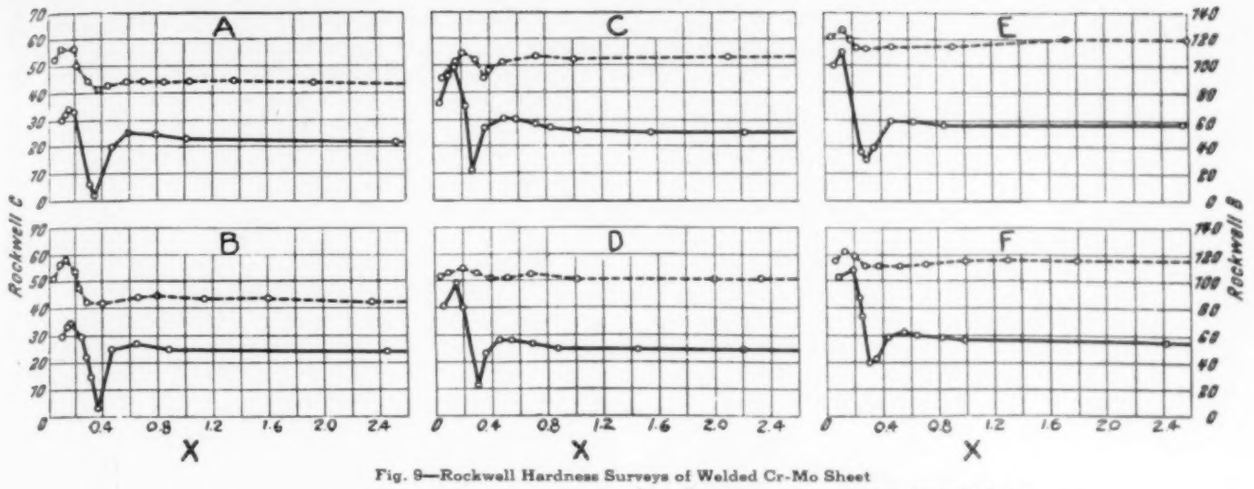

Fig. 9—Rockwell Hardness Surveys of Welded Cr-Mo Sheet

	C	Si	Mn	Cr	Mo	Al	Crack Sensitivity, % as Cold Rolled
A = Melt 7, ingot 1	0.26	0.54	0.64	1.10	0.20	..	0
B = Melt 7, ingot 3	0.25	0.54	0.56	1.07	0.18	0.01	0
C = Melt 4, ingot 1	0.30	0.38	0.58	1.02	0.31	0.04	0
D = Melt 4, ingot 3	0.31	0.38	0.57	1.02	0.32	0.10	16
E = Melt 5, ingot 1	0.42	0.34	0.64	1.22	0.40	..	0
F = Melt 5, ingot 2	0.41	0.31	0.63	1.22	0.37	..	0

X = Distance from weld, inches.
Bardenheuer and Bottenberg[110]
(Dotted line = annealed, Rockwell B)
(Full line = as-welded, Rockwell C)

the heat-affected zone of the low-carbon welds reached 400 in sheet 0.031 inch thick, 250 in sheet 0.188 inch thick. Measured from the center line of the weld, the width of the heat-affected zone was:

Sheet thickness, inch:	0.031	0.063	0.125	0.188
Width of heat-affected zone, inch:	6/32	7/32	18/32	24/32

Of the heat-treated weld-metals, Cr-Mo weld-metal had the same hardness as base metal; carburizing flux weld-metal was 20 to 100 Vickers below base metal; and low-carbon weld-metal was 150 to 200 below base metal. In the zone affected by welding the as-welded hardness was about 400 Vickers in the sheet 0.031 inch thick, and only 250 in the sheet 0.188 inch thick. Perhaps the thicker specimens cooled more slowly than the thin. According to Brueggeman (private communication, May 1938), the annealed zone in welded sheet is not so pronounced as in tubing because the tubing is more heavily cold worked. Probably the annealed zone in welded tubes also would be eradicated by normalizing. In oxyacetylene butt welded S. A. E. 4130 Ward[93] found Rockwell B 97 in unaffected base metal, B 75 in the zone of failure, B 110 in the air hardened zone, and B 57 in the low-carbon steel weld, which was, reenforced.

Rockwell hardness surveys of the oxyacetylene butt welded Cr-Mo sheets 0.04 inch thick tested by Bardenheuer and Bottenberg[110] (see Table 34) showed that the hard zone was 0.10–0.20 inch from the edge of the weld bead, Fig. 9. In the cold-rolled sheets there was always a zone of maximum softness beyond the zone of maximum hardness. The same zones appear in the welds made in sheet that had been heated 1/2 hr. at 650° C. (cooled in still air) before welding, but the differences in hardness in the zones were less pronounced. The hardness depended on heat treatment and the carbon, chromium and molybdenum contents, not on the phosphorous, sulphur or aluminum contents or other factors. The maximum hardness was 35 C Rockwell with 0.25 C and 50 C Rockwell with 0.41 C. Martensite always was found in the hard zone, which should not be subjected to mechanical work in fabricating processes.

The effect of carbon content on the hardness in the heat-affected zone was investigated by Zeyen,[101] Table 35, using the materials described in the section on Mechanical Properties. The indentations were made with a 2.5 mm. ball, 187.5 kg. load, after reinforcement and 0.004 inch of the sheet thickness had been ground away. The soft zone was not investigated. The erratic values determined for base metal close to weld illustrate the value of a systematic hardness survey in contrast with a single determination. The hardness of the weld appears to be an uncertain criterion of the location of failure in the tensile test. For example, the soft iron weld was much softer than steel 2, and the mild steel weld was much softer than steel 4 in the condition to which Table 35 applies. It would be difficult to believe that the softened zone of these steels would be less than 110 and 150 Brinell, respectively. Yet in the tensile tests with weld ground flush, both fractured outside the weld. Zeyen believed that his tests showed the advantage of decreasing the carbon content to 0.20–0.25 and increasing the chromium to 1.3–1.5 in S. A. E. 4130, on the grounds of creating less hardness in the heat-affected zone.

Table 35—Brinell Hardness of Oxyacetylene Welded Sheet 0.047 Inch Thick, Heat Treated Before Welding But Not Heat Treated After Welding. Zeyen,[101] (see Tables 26 to 29)

Steel	Filler Rod	Sheet	Brinell Hardness Base Metal Close to Weld	Edge of Weld	Middle of Weld
0.15 C, 0.88 Cr, 0.57 Mo	Base metal	143	167	219	198
	2% Cr	140	195	211	211
	Soft iron	135	156	115	125
	Mild steel	145	202	145	140
0.17 C, 1.48 Cr, 0.61 Mo	Base metal	167	224	211	207
	2% Cr	150	215	174	177
	Soft iron	153	164	110	117
	Mild steel	158	255	153	131
0.20 C, 1.30 Cr, 0.30 Mo	Base metal	234	249	272	244
	2% Cr	228	255	215	224
	Soft iron	219	187	170	133
	Mild steel	217	255	158	138
0.34 C, 1.03 Cr, 0.28 Mo	Base metal	224	292	285	272
	2% Cr	224	285	255	191
	Soft iron	224	239	131	115
	Mild steel	226	264	158	150

In agreement with Zeyen, Sutton[90] found a peak hardness of 289–292 in oxyacetylene butt-welded tubing

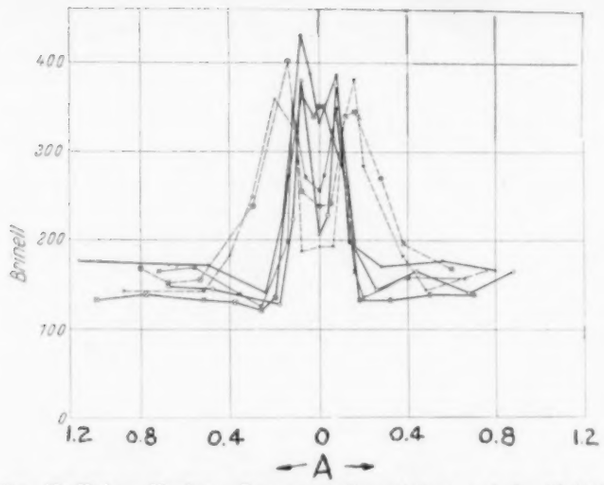

Fig. 10—Vickers Hardness Surveys of Oxyacetylene and Arc-Welded Cr-Mo Sheet 0.04 Inch Thick (see Table 14). Cornelius[79]

containing 1 Cr, 0.4–0.5 Mn, 0.20–0.27 Mo and 0.27 C and 310–360 Brinell in a similar steel containing 0.32 C. Maximum Brinell hardness of 350 to 380 near the weld is frequently observed, Sutton observed.

Correlation of hardness with microstructure was attempted by Müller,[97] Table 36.

The hardness of arc-welded Cr-Mo aircraft steel has not received much attention. Johnson[87] found, Fig. 7, that arc welding was likely to shift the softened zone closer to the weld than with oxyacetylene welding, and to create less softening. The Vickers hardness surveys made by Cornelius[79] on the welds described in the section on Mechanical Properties, Table 14, are reproduced in Fig. 10. There was no essential difference in the softening created by the two processes, but the heat-affected zone was much broader in the oxyacetylene welded joints. A maximum hardness of about 400 Vickers was attained in the 0.04-inch sheet welded by both processes. In the 0.08-inch sheet a maximum hardness of 464 Vickers was found in the arc-welded joints and 423 in the oxyacetylene welded joints. In a distance of 0.016 inch in the arc-welded joint the hardness jumped from 292 in weld-metal to 464 in base metal.

Table 36—Structure and Hardness of Oxyacetylene Welds in Aircraft Steels. Müller[97]

Steel	Wall Thickness Inch	Maximum Brinell Hardness	Structure	Tensile Strength, Lb./In.²	Bend Angle, Degrees
Plain carbon (0.33 C)	0.080	170	Coarse pearlite with Widmannstätten ferrite	71,000	90
Cr-Mo	0.040	250	Sorbitic "ferrite-pearlite"	85,000	90
Cr-Mo	0.040	350	Coarse martensite	91,000	40

The effect of welding speed on the maximum hardness of the heat-affected zone beneath a single bead (9 inches long) of a bare electrode $^5/_{32}$ inch diameter deposited automatically (A.C., 23 volts, 375 amps.) on the unmachined surface of a 9 × 2 × $^1/_2$-inch piece of normalized S. A. E. 4130 or 4150 was determined by Theisinger,[111] Table 37. The S. A. E. 4130 contained 0.33 C; the S. A. E. 4150 contained 0.52 C. The bead was run on the 9 inch x 2 inch surface parallel to the long edge. Up to a speed of 6 inches per minute the hardness increase is less for S. A. E. 4150 than for 4130. At speeds of 8 inches per minute the higher the hardness of S. A. E. 4150 increases very rapidly. The heat-affected zone of S. A. E. 4130 was sorbitic at speeds of 8 inches per minute and less, troositic at 12 inches per minute and martensitic (150 ×) at 18 inches per minute. The S. A. E. 4150 had "sorbite-troostite" in the heat-affected zone at 4 and 6 inches per minute, troostite and martensite at 8 inches per minute and martensite at 12 and 18 inches per minute. Theisinger did not attach any importance to the difference in chromium content between S. A. E. 4130 and 4150 (0.50–0.80 Cr in the former, 0.80–1.10 Cr in the latter), but attributed the great difference in hardening between the two steels to difference in carbon content.

Table 37—Maximum Hardness in Heat-Affected Zone as Affected by Welding Speed. Theisinger[111]

Steel	Base Metal	Maximum Vickers Hardness 4 In./Min.	6 In./Min.	8 In./Min.	12 In./Min.	18 In./Min.
S. A. E. 4130	208	236	232	240	270	470
S. A. E. 4150	286	302	302	330	550	640

The flame hardening of a circular bar of steel 2.4 inches diameter containing 0.35 C, 1.0 Cr, 0.2 Mo resulted in the hardness distribution shown in Fig. 11, according to Zorn.[112] Beneath the hard surface is a soft zone similar to the soft zone found in some welded aircraft tubing.

Metallography

The structure of welded Cr-Mo steel has been studied by Sisco and Boulton,[65] and by Cornelius and Bollenrath,[83] in particular. The structures observed by these and other investigators have been discussed in the two preceding sections, as well as in the following section on General Observations. The principal factors appear to be: (1) the grain size of weld-metal and base metal, (2) the presence of martensite in the heat-affected zone, (3) the structure of the soft zone, (4) the hardening characteristics of weld-metal and (5) the presence of non-metallic inclusions in weld-metal and base metal. The structure of chromium-molybdenum steels of S. A. E. 4100 type requires experience in interpretation and

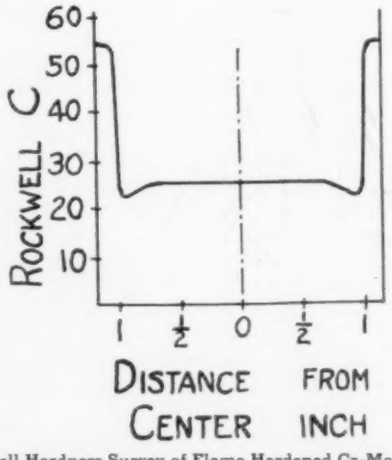

Fig. 11—Brinell Hardness Survey of Flame Hardened Cr-Mo Steel Shaft. The Shaft Was Heat Treated Before Flame Hardening and Was 2³/₈ Inches Diameter. Zorn[112]

preferably the support of hardness determinations to confirm the opinions of the microscopist. The printed micrograph is not always a trustworthy substitute for the original polished section. In the light of this caution only should the following conclusions be considered.

1. The grain size of weld-metal deposited by a Cr-Mo steel filler rod is finer than that deposited by a plain carbon rod under identical conditions. The important grain refining element is probably molybdenum, if deductions from steel mill and foundry experience on the grain refining influence of molybdenum is admissible. Nevertheless, Roosenschoon[113] stated that alloy steel filler rods produce no finer grain structure in the weld-metal than plain low-carbon steel rods in the oxyacetylene welding of Cr-Mo aircraft steel.

Generally Cr-Mo steel has been found to remain comparatively fine grained throughout the heat-affected zone. Doubtless, the speed and process of welding has some effect on the grain size in the heat-affected zone, but systematic investigations have not been made. Although Widmannstätten structure has been observed in the heat-affected zone of some Cr-Mo welds, the structure is by no means so pronounced as in plain carbon steels of the same carbon content. Anderson[114] believed that molybdenum is present in S. A. E. X4130 in order to restrain grain growth during welding (no details).

2. Investigators of the microstructure of welded Cr-Mo steel of S. A. E. 4130 type have usually been careful to point out that whilst a structure in these welds may look a little like martensite, it may etch more rapidly than martensite or lack the sharpness of detail that characterizes a structure containing martensite. Daniels[107] appears to have observed some martensite in the heat-affected zone of an oxyacetylene welded joint containing 0.32 C, 0.56 Mn, 0.93 Cr, 0.23 Mo. Other investigators have reported martensitic structures, but in the absence of X-ray or other confirmation it cannot be certain that martensite was present. All microstructures available in welded S. A. E. 4130 appear to be free at any rate from large aggregations of white martensite. The structure called martensite by Theisinger in his study of S. A. E. 4150 arc welded at 18 inches per minute has a different appearance from the structure called martensite in S. A. E. 4130 welded at the same speed.

Although chromium and molybdenum lower the critical cooling velocity of steel if they are in solid solution, the heat-affected zone during welding reaches a high temperature for so short a time that the grain size remains fine. According to accepted modes of reasoning, it may be supposed that the grain size remains fine because the chromium and molybdenum carbides or other compounds do not have time to dissolve in austenite. The austenite, therefore, is fine grained, low in chromium, molybdenum and carbon, and contains nucleating particles. All these factors favor shallow hardening and the absence of martensite in the heat-affected zone of welds in S. A. E. 4130.

3. The structure of the soft zone depends on the structure of the tube prior to welding. If the tubing is heat treated the soft zone is the zone which has received the maximum tempering effect and is sorbitic. If the tubing is cold drawn the sorbitizing effect will be accompanied by recrystallization. Obviously, if the tube were in the spheroidized condition before welding, the heat-affected zone cannot be softer than base metal.

4. The ability of Cr-Mo steel weld-metal to develop high strength upon being heat treated has been established by Zeyen,[101] in particular. Sisco and Boulton[65] showed that the structure of the heat-treated Cr-Mo weld-metal is nearly the same as heat-treated base metal. The ability to develop high properties in the heat-treated conditions depends on the cleanliness, grain size and composition of the weld-metal. In aircraft tubing the sections are thin and grain size is unimportant. To what extent chromium and molybdenum are recovered from the rod has not been studied. Cornelius[79] showed that dipped electrodes can deposit metal containing 0.1 C, 0.82 Cr, 0.21 Mo. There may be some loss of carbon, chromium and, perhaps, of molybdenum in oxyacetylene welding with a rod of base metal, depending on flame adjustment and other factors.

5. Non-metallic inclusions, such as sulphides, may have a bad effect on welded Cr-Mo steel but their rôle is still disputed. Bollenrath and Cornelius[84] observed films of material in the grain boundaries of a Cr-Mo weld containing 0.076 S. The question of non-metallic inclusions and cracks are discussed in the following section. Zeyen[115] found intergranular cracks in the heat-affected zone of an oxyacetylene welded steel that was sensitive to cracking. The cracks followed the grain boundaries of the original austenite grains.

Cracking

Welds in Cr-Mo aircraft steels sometimes crack during welding. The cracks generally appear in base metal very close to the weld (0.01 inch or so away). Sometimes they occur in the weld-metal. The methods of measuring the sensitivity of a steel to welding cracks were described in the review of literature on Shrinkage Stresses in Welding (AMERICAN WELDING SOCIETY JOURNAL, **16** (11) Research Supplement, 48–51 (1937)).

Müller[97] found that the crack sensitivity increased with the carbon content of the steel, Table 38. The sheets were rigidly gripped during welding. A slight cold stretching prior to welding increased the sensitivity of Cr-Mo steels to welding cracks. A Cr-Mo steel heat treated to a tensile strength of 171,000 lb./in.^{2} had no

Table 38—Crack Sensitivity of Cr-Mo Steel (1 Cr, 0.25 Mo, 0.5 Mn, 0.25 Si) in Oxyacetylene Welding. Müller[97]

Carbon content	0.20	0.27	0.28	0.31	0.33
Sulphur content	trace	..	..	..	trace
Crack sensitivity,* %	0	1	2	4	6

* % of length of weld occupied by cracks.

Table 39—Weld Crack Sensitivity of Cr-Mo Steels 0.043 Inch Thick. Zeyen[115]

Composition of Sheet			Fokker Bead Test Length of Cracks, In.		Focke-Wulf Bead Test Length of Cracks, In.		Cross Shaped Weld Test Length of Cracks, In.		Rigid Assembly Test % of Length Occupied by Cracks
C	Cr	Mo	Without Filler Rod	With Filler Rod	Without Filler Rod	With Filler Rod	As-Welded	Welded and Bent	
0.20	0.78	0.20	1.89	0.71	0.51	0.32	0.04	Crack not widened	24
0.28	0.90	0.21	1.97	1.06	2.87	1.10	0.95	Crack greatly widened	20
0.30	1.36	0.28	1.97	1.34	8.60	3.03	1.46	Cracks in two wings greatly widened; 2 wings broke	50

Table 40—Effect of Method of Refining on Weld Crack Sensitivity of Cr-Mo Steels 0.043 Inch Thick. Zeyen[115]

Method of Steel Refining	Composition of Sheet							Fokker Bead Test Length of Cracks, Inches		Focke-Wulf Bead Test Length of Cracks, Inches		Cross Shaped Weld Test Length of Cracks, Inches		Rigid Assembly Test % of Length Occupied by Cracks
	C	Si	Mn	P	S	Cr	Mo	Without Filler Rod	With Filler Rod	Without Filler Rod	With Filler Rod	As-Welded	Welded and Bent	
Basic open-hearth	0.28	0.31	0.71	0.011	0.015	0.90	0.21	1.97	1.06	2.87	1.10	0.95	Crack greatly widened	20
Basic open-hearth	0.28	0.27	0.52	0.011	0.017	1.09	0.21	1.97	0.83	3.15	2.20	0.87	" " "	24
Basic open-hearth	0.29	0.23	0.42	0.010	0.015	1.11	0.25	1.97	1.38	4.45	2.40	0.95	" " "	28
Basic open-hearth*	0.33	0.32	0.70	0.011	0.015	1.08	0.21	1.97	0.67	0.95	0	0.59	Cracks in two wings greatly widened; two wings broke	11
Arc furnace	0.27	0.25	0.49	0.016	0.010	1.08	0.21	1.50	0.75	0.32	1.34	0.12	Cracks not widened	0
Arc furnace	0.28	0.24	0.54	0.015	0.010	1.00	0.23	1.97	0.67	0.59	0.16	0.35	Cracks barely widened	0
Arc furnace	0.29	0.21	0.50	0.016	0.010	1.00	0.23	1.97	1.22	0.51	0.63	0.43	Cracks widened a little	0
Arc furnace*	0.24	0.18	0.48	0.011	<0.010	1.06	0.21	0.16	0.04	0	0	0.08	Cracks not widened	0

* Special refining treatment.

greater crack sensitivity than the same steel annealed to 85,000 lb./in.[2] Müller also stated that cracking increased as the sulphur and phosphorous content of the steel was increased. He stated that the total sulphur and phosphorous content of Cr-Mo steel should not exceed 0.035%. Other investigators differ from Müller on the sulphur and phosphorous question, which, however, is discussed in the reviews of literature on Sulphur and Phosphorus in the Welding of Steel.

Zeyen[115] confirmed Müller's results on the serious effect of increasing carbon content on crack sensitivity. Table 39 shows that steels made by the same process (no details) increase in crack sensitivity (averages of 6 determinations, oxyacetylene) as the Cr, Mo and particularly the carbon content increases. However, the method of refining the steel also has a great influence on sensitivity to welding cracks, Table 40 (averages of 6 determinations, oxyacetylene). Arc furnace steels of practically the same composition as basic open-hearth melts were much less sensitive to welding cracks. Special refining treatment (no details) of both open-hearth and electric furnace steels also may reduce the crack sensitivity. It has been Zeyen's[116] experience that the special refining treatment that may have a good effect on the crack sensitivity of small melts (110 lb.) may have a different effect on large melts (22 tons).

Eilender and Pribyl[117] found that specially melted and deoxidized steel, Table 41, gave no cracking in Focke-Wulf tests (0.04-inch sheet). It should be observed that the specially refined Cr-Mo steels generally have a higher manganese content than ordinary Cr-Mo steels. The melts were made either in a basic high-frequency furnace (110-lb. ingots) or in a gas-fired crucible furnace (220-lb. ingots). The melts contained up to 0.36 C, 2.21 Mn, or 0.036 P. The sum of sulphur and phosphorus reached 0.053%. The low sulphur content could not be avoided in the overheated melts under the conditions of steel making. A sheet that had been carburized to an average carbon content of 0.46%, eutectoid surface layer, was insensitive. The high-manganese steel, 0.35 C, 2.21 Mn, was also completely insensitive, although air cooling hardened the steel to C 50 to C 55 Rockwell.

Eilender and Pribyl interpreted their results on the basis of absence of segregation in the specially melted or specially deoxidized steels. The cracking during welding was believed to occur at 650° C. (visual observation in clamp tests) and to be caused by decreased capacity for deformation at 600 to 700° C. owing to segregation in the sheet. The specially treated steels had small particles distributed through them which initiated solidification at many nuclei. Segregation was avoided because the grain size of the ingot just after solidification was small and the diffusion path for homogenization was correspondingly small. No measurement of the grain size of the ingot was made. The calcium-silicon contained 31% Ca, 61% Si.

Apart from the effect of grain size in the ingot on elimination of segregation, grain size had no effect on crack sensitivity. Insensitive sheets heated 2 hr. at 950, 1050, 1150 or 1250° C. had coarse grain structure and were decarburized so that the surface contained 0.26% C, the interior 0.31% C, but remained insensitive. On the other hand, sensitive steels heated 24 hr.

Table 41—Composition of Cr-Mo Steels That Were Not Sensitive to Oxyacetylene Welding Cracks in Focke-Wulf Clamp Tests. Eilender and Pribyl[117]

Method of Melting and Deoxidizing	Chemical Composition—%						
	C	Si	Mn	P	S*	Cr	Mo
Overheated	0.28	0.31	0.60	0.012	0.015	0.97	0.19
"	0.22	0.35	0.46	0.016	0.012	0.67	0.28
"	0.23	0.23	0.63	0.020	0.012	0.67	0.24
"	0.32	0.33	0.69	0.036	0.005	0.98	0.21
"	0.35	0.33	0.65	0.032	0.003	1.04	0.17
"	0.36	0.27	0.68	0.030	0.004	0.97	0.16
"	0.35	0.27	2.21	0.027	0.017	0.95	0.20
"	0.31	0.25	0.93	0.030	0.008	0.95	0.20
First and final deoxidation with calcium-silicon	0.34	0.25	0.60	0.014	0.023	0.96	0.20
First and final deoxidation with calcium-silicon	0.33	0.21	0.73	0.034	0.014	0.95	0.21
First and final deoxidation with calcium-silicon	0.30	0.18	0.86	0.034	0.019	0.95	0.20
First deoxidation with Al; final deoxidation with calcium-silicon	0.24	0.19	0.88	0.033	0.017	0.94	0.20
First deoxidation with Al; final deoxidation with calcium-silicon	0.30	0.25	0.81	0.031	0.022	0.95	0.21
Simultaneous deoxidation with ferromanganese and ferrosilicon	0.29	0.24	0.77	0.034	0.017	1.00	0.21
Simultaneous deoxidation with ferromanganese and ferrosilicon	0.28	0.20	0.81	0.033	0.021	0.92	0.19
First deoxidation with aluminum; final deoxidation simultaneously with ferromanganese and ferrosilicon	0.25	0.20	0.73	0.036	0.020	0.95	0.18
First deoxidation with aluminum; final deoxidation simultaneously with ferromanganese and ferrosilicon	0.25	0.21	0.78	0.032	0.015	0.97	0.20

* By solution method, which yields low results.

Table 42—Charge, Composition and Degree of Weld Sensitivity of the Steels Used by Bollenrath and Cornelius[51]

Steel No.	Charge	C %	Si %	Mn %	Cr %	Mo %	N_2 %	O_2 %	H_2 %	P %	In Ingot: V^1 [a]	In Ingot: V^2 [b]	In Ingot: V^2 [a]	In Plate or Tube: V^1 [c]	In Plate or Tube: V^2 [c]	In Plate or Tube: V^2 [d]	In Plate or Tube: V^1 Average	Crack Sensitivity %: Gas	Crack Sensitivity %: At Hyd.	Remarks
Tubes 1.18 in. Diam., 0.039 inch Wall Thickness from 90 lb high frequency furnace melts. Basic lining.																				
11	Basic Bessemer Scrap	0.26	0.23	0.64	1.06	0.29	—	—	—	0.010	—	—	0.027	0.024	0.031	—	0.027	0.6	—	Crack Sensitivity for Gas Welding, see total average from Table 2. Atomic Hydrogen Average of at least 4 tests
12	Open Hearth Scrap	0.25	0.24	0.62	1.01	0.31	0.0121	0.007	0.00013	0.010	—	—	0.026	0.024	0.031	—	0.027	0.6	—	
13	Armco Iron	0.25	0.27	0.63	0.98	0.29	—	—	—	0.011	—	—	—	0.024	0.029	—	0.0265	6.0	0	
14	Basic Bessemer Scrap	0.25	0.26	0.68	1.08	0.29	0.0127	0.003	0.00046	0.010	—	—	—	0.021	0.021	—	0.021	0	—	
15	Armco Iron	0.26	0.27	0.70	0.94	0.28	0.0158	0.0038	0.00029	0.012	—	—	—	0.026	0.024	—	0.025	0.4	—	
16	Open Hearth Scrap	0.25	0.27	0.72	1.05	0.28	—	—	—	0.011	—	—	—	0.027	0.029	—	0.028	0.4	—	
17	Basic Bessemer Scrap	0.27	0.25	0.70	1.09	0.29	0.0062	0.005	0.00026	0.012	—	—	—	0.031	0.031	—	0.031	5.7	0	
18	Open Hearth Scrap	0.27	0.30	0.57	1.06	0.29	—	—	—	0.010	—	—	—	0.024	0.027	—	0.0255	2.6	—	
19	Basic Bessemer Scrap	0.26	0.30	0.61	1.06	0.28	—	—	—	0.012	—	—	—	0.027	0.025	—	0.026	4.6	0	
20	Chromium - Molybdenum Steel Scrap	0.23	0.25	0.64	1.12	0.28	—	—	—	0.014	—	—	—	0.024	0.027	—	0.0255	4.3	—	
21	Basic Bessemer Scrap	0.26	0.27	0.56	1.01	0.29	0.0157	0.0073	0.00016	0.014	—	—	—	0.027	0.030	—	0.0285	13.0	0	
22	Chromium - Molybdenum Steel Scrap	0.25	0.20	0.50	0.89	0.28	0.015	0.0053	0.00016	0.012	—	—	—	0.024	0.027	—	0.0255	16.0	0	
Sheets 0.039 inch thick, from 20 lb high frequency furnace melts. Acid furnace lining.																				
23 k[d]	Soft Iron	0.33	0.32	0.43	1.08	0.29	0.006	0.0255	0.00032	0.010	0.017	—	0.014	—	—	—	0.014	9	0	No Nickel detected in any steel.
24 k		0.31	0.30	0.57	1.20	0.32	—	—	—	0.010	0.016	—	0.013	—	—	—	0.013	2.3	0	
25 k		0.18	0.25	0.43	0.84	0.32	—	—	—	0.006	0.005	—	0.016—0.017	—	—	—	0.0165	0	0	
26 h		0.29	0.25	0.52	0.89	0.32	0.0062	0.0195	0.00033	0.016	0.031	—	0.023—0.030	—	—	—	0.0275	18	0	
27		0.32	0.32	0.76	0.92	0.32	0.0076	0.015	0.00047	0.011	0.035	—	0.033	—	—	—	0.033	13	0	
28 h		0.31	0.23	0.49	0.96	0.25	—	—	—	0.013	0.045	0.044	—	—	—	0.043	0.043	15	0	
29 h		0.25	0.24	0.49	0.91	0.33	0.0048	0.018	0.00027	0.013	0.007	—	—	—	—	0.014	0.014	0	0	
30 h		0.25	0.26	0.62	0.98	0.31	0.0074	0.0155	0.00032	0.012	0.018	0.026	—	—	—	0.025	0.025	0	0	
31		0.23	0.20	0.49	1.02	0.28	0.0057	0.0135	0.00044	0.013	0.012	0.017	—	—	—	0.016	0.016	0	0	
32 u		0.33	0.26	0.54	0.98	0.32	—	—	—	0.012	0.020	0.025	—	—	—	0.026	0.026	0	0.5	
33		0.30	0.33	0.56	0.99	0.30	0.0075	0.0195	0.00016	0.012	0.034	0.037	—	—	—	0.040	0.040	38	0	
34 Al, h		0.26	0.18	0.48	0.98	0.31	0.0070	0.0076	0.00017	0.014	0.009	0.021	—	—	—	0.020	0.020	1	0	
35 Al, h		0.27	0.19	0.48	0.95	0.30	0.0082	0.0087	0.00014	0.013	0.014	0.031	0.035	—	—	0.034	0.0345	12	1.5	
36 k		0.24	0.26	0.49	0.98	0.30	0.0072	0.017	0.0003	0.042	0.009	0.015	0.016	—	—	0.014	0.015	0	0	
37 k		0.24	0.26	0.49	0.91	0.30	0.0068	0.0165	0.00035	0.033	—	—	—	—	—	0.014	0.014	0	0	
38		0.23	0.23	0.40	0.96	0.29	0.0086	0.016	0.00051	0.020	0.034	0.036	—	—	—	0.039	0.039	8	0	
39		0.34	0.29	0.58	1.16	0.29	0.0082	0.013	0.00034	0.012	0.018	0.030	—	—	—	0.029	0.029	8	0	
40		0.28	0.19	0.48	1.01	0.24	—	—	—	0.012	—	—	—	—	—	0.037	0.037	0	0	
41 h		0.28	0.18	0.42	0.94	0.28	0.0081	0.016	0.0005	0.043	—	—	0.016	—	—	0.014	0.015	16	0.3	
Tubes 1.18 inches diameter, 0.039 inch wall thickness, made from 11 to 12-ton electric furnace melts.																				
42		0.24	0.21	0.60	0.96	0.19	0.0055	0.005	0.0003	0.013	—	—	—	—	—	0.021	0.021	0	—	0.1 % Ni
43		0.24	0.22	0.64	0.98	0.20	0.0068	0.005	0.00025	0.011	—	—	—	—	—	0.016	0.016	0	—	0.09 % Ni
44		0.26	0.15	0.62	0.97	0.18	0.0039	0.006	0.0002	0.014	—	—	—	—	—	0.010	0.010	0.3	—	0.10 % Ni

[a]—Solution method. V^2—Combustion method at 1200° C. [b]—Bollenrath and Cornelius' values. [c]—Federal Bureau of Testing Materials, Berlin-Dahlem. [d]—Steel mill 1. [e]—Steel mill 2. k—Cast cold. h—Cast hot. u—Melt overheated, cast at normal temperature. Al—0.1% Al added to the furnace previous to casting. Nitrogen analysis was by Wüst and Duhr modification of Kjeldahl method; oxygen and hydrogen by vacuum fusion

at 1270° C. became insensitive, because the heat treatment eliminated segregation. Despite the fact that the killed steels in Table 41 had a coarse McQuaid-Ehn grain size and were deep hardening, they were free from segregation and, therefore, had excellent welding qualities. Like Zeyen, Bollenrath and Cornelius[118] found that welding cracks in the ferrite-sorbite area are intercrystalline, which suggests that the cracks formed at elevated temperatures. Tensile tests on Cr-Mo aircraft steels (strips 0.04 x 0.79 inch cross section, 4-inch gage length) conducted at a speed of 0.04 inch per minute at temperatures up to 1000° C. revealed that the elongation was only 15% in 4 inches at 1000° C. (tensile strength 5000 lb./in.²) but was 40 to 60% in 4 inches at 800° C. The tensile fractures at 1000° C. were intercrystalline and had the same appearance as welding cracks.

Rigid assembly crack sensitivity tests, Table 42 showed that the nature of the scrap in the charge had an important effect on cracking. The 40-kilogram test melts were melted in the basic high frequency induction furnace without special slag. The charge consisted of basic Bessemer open-hearth and chromium-molybdenum steel scrap, and also Armco iron. The charge was chosen in such a manner that the melts ran reasonably high in carbon so that the carbon content in the melt had to be increased only very slightly or not at all. Additions to the melts were ferromanganese, ferrosilicon, ferrochromium and ferromolybdenum. The melts were not killed by aluminum additions. The composition of the high frequency furnace melts was controlled by additions or iron sulphide and ferrophosphorus. Weld cracking in excess of 1% was indicated by:

3 out of 5 melts with 0.25 to 0.27% carbon and 0.021 to 0.031% sulphur, with Bessemer scrap.

1 out of 3 melts with 0.25 to 0.27% carbon and 0.0255 to 0.028% sulphur, with open-hearth scrap.

1 out of 2 melts with 0.25 to 0.26% carbon and 0.025 to 0.0265% sulphur, with Armco iron scrap.

Both melts with 0.23 to 0.25% carbon and 0.0255% sulphur, with Chromium-Molybdenum steel scrap.

Open-hearth scrap produced steel with the least sensitivity to cracking; Cr-Mo steel scrap was the worst. In addition to the influence exerted by the charge, there is an indefinite effect due to sulphur. Decided overheating of the melt followed by pouring at the correct temperature decreased the sensitivity of a steel whose composition was unfavorable (No. 32, Table 42). There is no definite evidence that casting temperature is important for crack sensitivity. All in all, the results show that if the steel contains up to 0.02 S and up to 0.025 P at 0.23 to 0.27 C, 0.5 to 0.7 Mn max., 0.3 Si, 0.9 to 1.1 Cr, and 0.15 to 0.25 Mo, there should be no difficulty with cracking during oxyacetylene welding, especially with steel made in the mill rather than with experimental melts. With atomic hydrogen welding sulphur up to 0.043% is not a factor.

Cr-Mo steels 0.04 inch thick made in the high frequency furnace can be atomic hydrogen welded in a rigid assembly without cracking even with 0.31 to 0.34 C. Although the speed of atomic hydrogen welding was the same as oxyacetylene, the heated zone was 20 to 25% smaller. The total oxygen, hydrogen and nitrogen contents of the steels as well as normalizing prior to welding had no effect on crack sensitivity.

As a general rule sensitivity to cracking increases as wall thickness decreases. Nevertheless, cracking of oxyacetylene butt-welded Cr-Mo tubing (0.27 C, 0.29 Si, 0.53 Mn, 0.92 Cr, 0.23 Mo, 0.14 Cu, 0.012 S, 0.019 P)

Table 43—Effect of Method of Welding on the Crack Sensitivity (Focke-Wulf Test) of Cr-Mo Steels. Cornelius[119]

No.	Specimen*	Composition of Steel, % C	Mn	P	S	Cr	Mo	Oxyacetylene Cracks, %	Oxyacetylene Depth of Crack, %	Atomic Hydrogen Cracks, %	Atomic Hydrogen Depth of Crack, %	Metal Arc Cracks, %	Metal Arc Depth of Crack, %
1	Tube	0.23	0.60	0.020	0.005	1.00	0.24	0	0	0	0	0	0
2	Sheet	0.26	0.50	0.011	0.017	1.06	0.21	0.7	50	0	0	0	0
3	Sheet	0.26	0.50	0.034	0.033	1.06	0.21	57	100	32	50 to 100	0.8	50
4	Sheet	0.26	0.50	0.013	0.029	1.06	0.21	3	50 to 100	0.2	25	0	0
5	Sheet	0.26	0.50	0.034	0.043	1.06	0.21	58	100	15	100	1	25
6	Sheet	0.25	0.52	0.011	0.048	0.98	0.33	46	100	..	...	0.8	25

* Tube was 0.04-inch wall, 1.10 inches o.d.; sheet was 0.04 inch thick.
Cracks are expressed as percentage of length of weld; depth of cracks as percentage of thickness of steel.
Sheets 2 to 5 were made from the same heat with different additions of sulphide and phosphide. Sheet 6 was made from a suphurized arc-furnace heat.

30 inches diameter, 0.20-inch wall thickness always occurred, as in thin-walled tubing, immediately adjacent to the weld and on the inside of the tube. The cracks were 0.04 inch deep. A Cr-Mo filler rod was used and the joint was made in two layers, 50° V with 0.04-inch reinforcement on the inside.

The fact that Cr-Mo aircraft steels are less sensitive to cracking in the rigid assembly test with atomic hydrogen welding than with oxyacetylene was confirmed by Cornelius[79] in later work. Metal arc welding (see Table 43) was even better than atomic hydrogen welding from the standpoint of cracking. In rigid assembly tests of sheet containing 0.26 C, 0.5 Mn, 0.034 P, 0.043 S, 1.06 Cr, 0.21 Mo, the length of cracks expressed as percentage of the total length of the butt weld was 58% with oxyacetylene welding, 15% with atomic hydrogen welding and 0 to 4% with metal arc welding. Cornelius stated that hydrogen is probably not a factor in causing welding cracks in Cr-Mo steel since atomic hydrogen welding leads to less cracking than oxyacetylene. Still, both processes involve hydrogen in the welding atmosphere. Nevertheless, Cornelius appears correct in attributing the differences in cracking among the three welding processes in rigid assembly tests to the differences in heat input, arc welding producing the narrowest heat-affected zone and the least cracking due to reaction stresses. The Fokker test was not applied to arc welding.

Hydrogen appealed to Bardenheuer and Bottenberg[110] as the basic cause of sensitivity to welding cracks in Cr-Mo aircraft steel. Their steels, Table 34, were prepared in either an arc furnace lined with magnesite (basic melts) or a sand-lined coreless induction furnace (acid melts). The melts weighed 440 lb. and were poured from a ladle into 100-lb. ingots. The ingots were hot rolled to 0.16 x 24 x 91 inches, annealed at 850° C., and cold rolled to 0.04 inch in five passes with an intermediate anneal. None of the sheets showed any defects. Half of each sheet was heated $^1/_2$ hr. at 650° C. and cooled in still air.

For crack sensitivity tests the Focke-Wulf clamp test was used (strips 2 inches wide, $2^3/_4$ inches long rigidly clamped and oxyacetylene welded with purified tank gases and a rod containing 1.8% Ni; about 1 gm. of rod was used for each weld). All specimens were backhand welded by the same welder at constant speed, and were cooled in still air in the clamp. The weld was bent back and forth in a wire tester until fracture occurred. The percentage of the fractured surface occupied by heat-tinted zones was termed the crack sensitivity. Radiographs revealed the same crack sensitivity as the fractured surface.

The temperature at which cracks became visible on the specimens was measured by means of thermocouples (wire 0.004 inch diameter) embedded 0.12 inch from the weld. The temperature varied from 600 to 700° C., which was close to the A_1 points of the steel: 662 and 724° C. (Eilender and Pribyl[117] also placed the temperature at which cracks appear in Focke-Wulf tests at 650° C. (no details), but Cornelius[119] pointed out that the temperature at which the cracks occurred was probably higher; 800° C., than the temperature at which they became visible.) The cracks were believed to be due to the stresses created by the zonal change of the heat-affected zone to martensite or pearlite, depending on the maximum temperature attained by the zone during welding. Hydrogen has a great effect on the cracking of steel during the Ar transformations.

Crack sensitivity tests on 60° V oxyacetylene butt welds in 0.16-inch plates, Table 44, showed that the pick up of hydrogen during welding is greater for the sensitive steels than for the insensitive steels, and that the hydrogen content of base metal is hardly an important factor. The hydrogen-soaked melt No. 13 also showed that hydrogen had ample time to diffuse from the steel during processing and so had no effect on crack sensitivity.

Table 44—Effect of Hydrogen on Crack Sensitivity of Cr-Mo Steel 0.16 Inch Thick in Oxyacetylene Welding. Bardenheuer and Bottenberg[110] (see Table 34)

Melt No.	Ingot No.	Crack Sensitivity, % Unannealed	Crack Sensitivity, % Annealed	Hydrogen Content,† Cm.³/100 Gm. Base Metal*	Hydrogen Content,† Cm.³/100 Gm. Weld	Increase in Hydrogen Content as a Result of Oxyacetylene Welding, Cm.³/100 Gm.
3	1	0	0	0.25	1.59	1.34
5	2	0	0	0.38	1.62	1.24
7	1	0	0	0.22	2.08	1.86
7	2	0	0	0	2.04	2.04
12	3	0	0	0	1.27	1.27
13	2	0	0	0	1.03	1.03
	Average			0.14	1.61	1.46
2	1	15	7	0.31	3.04	2.73
2	4	57	64	0.10	1.81	1.71
3	2	7	25	0.27	2.48	2.21
3	4	52	69	0.15	1.87	1.72
4	3	16	2	0.21	2.36	2.15
	Average			0.21	2.31	2.10

* Sections 0.28 inch outside the weld
† Evolved at 400° C.

More striking results were secured with insensitive plates that had been cathodically charged with hydrogen and welded at once. After being charged for 30 min. the plates increased in crack sensitivity from 0 to 15%, which steadily rose to 42% as the time of charging was increased to 5 hr. If the plates charged 5 hr. were allowed to remain in air for a period of time before welding, the crack sensitivity steadily decreased until, after a rest of 50 hr., the crack sensitivity was zero once again.

The tests show that hydrogen in the steel during welding and subsequent cooling is an important factor in cracking. Observation of flakes in alloy steels showed that hydrogen is more effective in cracking coarse-grained steel than fine-grained, and in cracking steels with inclusions of oxide or oxygen compounds than pure steel. In both instances, the pressure of hydrogen is greater in the more sensitive steel. With coarse grain the evolved hydrogen has less grain boundary volume in which temporarily to expand and, therefore, creates higher pressures than in fine-grained steels. Oxide inclusions provide pockets to combine with and retain the gas within the steel and create stress concentrations, rather than to permit diffusion from the steel, the gaseous hydrogen compounds having a lower diffusion rate through steel than hydrogen itself. High oxide content coincided with high crack sensitivity, which is in agreement with the hydrogen hypothesis.

McQuaid-Ehn tests (carburization for 8 hr. at 927° C.) showed in general that the 0.16-inch plates which were insensitive were abnormal, whereas the plates with high crack sensitivity were normal. Aluminum-killed steels that were resistant to grain growth on overheating and resistant to aging were also insensitive to welding cracks. But resistance to grain growth at welding temperatures was found to depend on furnace procedure even more than on aluminum content. The grain size of specimens from a number of the ingots heated as high as 1050° C. was fine. However, ingot 3 from melt 4 (0.10 Al) became coarse-grained at 1300° C., whereas ingot 1 from melts 4 and 6, particularly the latter, remained fine-grained and tough.

Returning to Table 34, it is seen that the working of the melt, but not the type of furnace, had a great effect on crack sensitivity. Melts 1 to 4 which were worked at low temperature without boil were sensitive. Increase in carbon, phosphorus and sulphur increased the sensitivity. If phosphorus and sulphur were low, an increase in carbon had no effect on sensitivity. On the other hand, melts 5 to 13 were worked hot and boiled. They were insensitive unless the phosphorous or sulphur content was extraordinarily high, or unless aluminum was added, ingot 2 melt 11. Cold-working or heat treatment (oil- or water-quenched from 850° C. followed by air cooling from 550, 500 or 700° C.) had no effect on sensitivity. There was no connection between the hardness of the joint as revealed by Rockwell surveys and the crack sensitivity, but the cracks occurred in the zone of maximum hardness. Dr. Cornelius also reports (private communication, May 1938) that sheets 0.04 inch thick of different alloy steels which developed over 500 Brinell in the heat-affected zone after welding were not found to be sensitive to cracking. Consequently, the hardness of the joint in thin sheet does not affect cracking.

The investigators[110] concluded that crack sensitivity is decreased by

1. Long and active boiling of the melt to decrease the oxide content (most important);
2. Low content of carbon, aluminum, sulphur and phosphorus;

but is not affected by

1. Charge
2. Casting temperature
3. Cold work
4. Heat treatment
5. Hardness of weld.

The conditions for crack sensitivity suggest that hydrogen absorbed during welding creates the stresses which, superimposed on the stresses created during the zonal transformation of austenite to martensite and pearlite, crack the steel. The hydrogen creates high stresses if the grain size is large or, more important, if the steel contains non-metallic inclusions of oxide nature.

Leaving the realm of quantitative measurements, we may now consider a number of more or less accurate observations and hypotheses on the subject of cracking. Whittemore and Brueggeman[103] found that cracks in their specimens occurred very close to the weld, sometimes at the very junction between weld and base metal. The cracks were said to be caused by residual stress (no details) during cooling. Cracking was particularly troublesome in welding gusset plates. In the later N. A. C. A. tests, Brueggeman[81] had no difficulty with cracking in sheets, but all welded specimens of thin-walled Cr-Mo tubing welded with the low-carbon filler rod, Table 16, contained intercrystalline cracks, which were partly filled with oxide, were usually $^1/_2$ inch long, and were parallel to, and about $^1/_{32}$ inch away from, the weld. These cracks could not be avoided by any change in welding technique short of using the carburizing flux method with special rod. No difficulty with cracking was observed with the carburizing flux method. It should be emphasized that cracks occurred only in tubing $1^1/_2$ inches o.d., 0.020-inch wall.

Discussing Downe's[105] paper, Seeman stated that heating the steel to a dull red relieves internal stress in S. A. E. X4130 tubing. The stress-relieved tubes do not crack during welding. He also stated that the welding of S. A. E. X4130 away from an edge instead of toward it is one of the most prolific sources of cracks. Clayton believed most of the cracking trouble was caused by the grades of S. A. E. X4130 having the higher tensile strengths. Sand blasting the edges to be welded decreases cracking, according to Somers. In Clement's opinion air hardening causes the cracks, the lower the temperature of the austenite transformation the greater being the stresses created by the dimensional changes. Consequently, thin-walled tubing with air hardening elements on the high side of the specifications (S. A. E. X4130) gives the most trouble. The thinner the sheet the more difficult it is to avoid welding cracks, 0.035 inch being the practical minimum thickness.

Discussing Bollenrath and Cornelius'[84] investigation, Rapatz conjectured that there was a relationship between the sensitivity of a steel to overheating and sensitivity to welding cracks. The bad effect of non-metallic inclusions in Cr-Mo steel increases with the grain size. Absence of segregation, according to Eilender and Pribyl is desirable in promoting ductility at elevated temperatures, and in avoiding welding cracks.

Werner's discussion was based particularly on the supposed action of some elements (sulphur and, possibly, oxygen) in steel and raising the Ar3 temperature (austenite transformation temperature) to 600 or 700° C. where the ductility of Cr-Mo steel is low. It should be noted that the tensile tests made by Bollenrath and

Table 45—Effect of Carbon and Sulphur Content on Sensitivity of Cr-Mo Steels to Welding Cracks. Werner (discussion of reference[84])

Carbon Content	Sensitivity to Welding Cracks Occurs at: Electric Furnace Steels	Basic Open-Hearth Steels Manufactured by a Special Method Involving Deoxidation by Manganese
0.15	0.035% S	0.050% S
0.20	0.030% S	0.043% S
0.25	0.025% S	0.035% S
0.30	0.020% S	0.030% S
0.35	0.015% S	0.025% S

Cornelius[118] indicated that the ductility of Cr-Mo steel is unusually good in the temperature range of 600 to 800° C. French and Tucker's tensile tests on normalized unwelded steel containing 0.27 C, 0.62 Mn, 0.26 Si, 0.008 S, 0.018 P, 0.99 Cr., 0.41 Mo up to 550° C. showed that the elogation and reduction of area increased steadily with rise in temperature from a minimum at 275° C. Nevertheless, Werner's tests, Table 45, which were conducted at the German National Materials Testing Laboratory, showed a clearer relationship between sulphur content and cracking than had been found by Bollenrath and Cornelius. The electric furnace steels contained 0.3 Si, 0.5 Mn, 1 Cr, 0.25 Mo. The special basic open-hearth steels contained 0.18–0.30 Si, 0.85–1.3 Mn, 0.63–1.02 Cr, 0.37–0.46 Mo. The sheets were 0.04 inch thick and were tested in a rigid assembly device (no details). An arbitrary value was assigned to weld sensitivity (no details) according to which a steel was considered sensitive to cracks if they almost invariably occurred in the test.

The beneficial effect of manganese was believed to be due to its effect in depressing the austenite transformation to lower temperatures at which the steel was supposed to be more ductile, and in spreading the transformation over a range of temperatures. Carbon has the same effect as manganese, but an increase in Mn from 0.5 to 1.2% has a much greater effect on the hysteresis of Ar3 than an increase in carbon content from 0.15 to 0.35%. Besides, an increase in carbon content renders the Cr-Mo steel more subject to micro-cracks during the austenite transformation on cooling. Many of Werner's assumptions are either faulty or unfounded, but his comprehensive view of the cracking problem is admirable. Unfortunately, he did not report the mechanical properties of his Mn-Cr-Mo steels.

Phillips[120] traced all cracking in welded Cr-Mo aircraft steel to excessive contraction (no details), but observed that cracks tend to run across the rolling grain of the material. Consequently, the more important welds should be made parallel to the rolling grain. A deposit of copper on Cr-Mo sheet for rolling purposes or from a $CuSO_4$ dip was found to cause welding cracks. The sheet should be steel blasted before being welded. Birdsall[121] confirmed Phillips' observations on the bad effect of a copper coating. Perhaps the copper melts in advance of the steel, penetrates between the grains of austenite and so causes cracks. A similar explanation may apply to Johnson's strong caution against welding near a brazed or soldered joint. Petrov and Plutschek[122] attributed cracks in arc welds in steel 0.06 and 0.39 inch thick containing 0.31 C, 0.6 Mn, 0.25 Si, 0.03 S, 0.03 P, 0.91 Cr, 0.15 Mo to nitrides picked up during welding.

Shrinkage stresses in welded Cr-Mo aircraft tubing were measured (X-ray) by Möller and Roth[123] (see review of literature on Shrinkage Stresses in Welding). Roosenschoon[113] stated that shrinkage stresses in Cr-Mo welds sometimes reduce the fatigue strength below welds in unalloyed steels (no details).

Discussion

On no other steel do we have so much information about welding cracks as on the Cr-Mo aircraft steels. From their blued appearance and intercrystalline nature it is a fair conclusion that the cracks usually occur well above room temperature, probably 500 to 1300° C. The cracks are formed by reaction or welding stress acting on the hot steel close to the weld. The hot steel is in a weak and relatively brittle condition. Sometimes the cracks are visible on the surface, sometimes they are wholly internal. Usually a crack that reaches the surface is entirely blued, which probably indicates that the crack does not propagate at low temperatures.

Investigators differ on the temperature at which the cracking occurs. No entirely convincing measurements have been made of the temperature at which the cracks occur on account of the difficulty in detecting the cracks even after the joint has cooled. There is Brueggeman's observation that the cracks are sometimes scaled to support the belief that the cracking temperature is at least red heat. In the absence of more persuasive evidence it must be admitted that the cracking temperature is not known.

If the cracking temperature is assumed to be about 1000° C., the crack may be due to shrinkage stress acting on the Cr-Mo steel when it is in a condition of low strength and ductility. Bollenrath and Cornelius' discovery that Cr-Mo steel (and plain carbon steel) in sheet form has surprisingly low ductility at 900 to 1000° C. has not been verified by tests on other steels. But other investigators of the high temperature properties of Cr-Mo steel have not used sheet specimens. Bollenrath and Cornelius showed that bars of Cr-Mo steel $^3/_8$ inch diameter do not lose their ductility at 900 to 1000° C. to nearly so great an extent as sheet specimens 0.04 inch thick. Since their experiments did not extend beyond 1000° C. it is not certain whether the steel becomes more or less ductile at higher temperatures.

Bollenrath and Cornelius were inclined at one time to believe that the relative brittleness at 900 to 1000° C. could be attributed to the sulphur content of the steel. Yet their steels containing 2.26 Mn, 0.13 C exhibited high temperature brittleness and the Cr-Mo steels that were tested had over 0.5 Mn, which is adequate to prevent the formation of iron sulphide. Furthermore, the effect of annealing a high-sulphur cast steel with iron sulphide in the grain boundaries for a long time at 1000° C. is to spheroidize the sulphide and render the steel more ductile. Consequently, the fact that sulphides have been observed in one unusual instance in the grain boundaries near welds in Cr-Mo steel does not provide an explanation for brittleness at 900 to 1000° C. in unwelded steel. However, if grain boundary inclusions (sulphides) are observed in the vicinity of a welding crack, they very likely were the cause of the crack. Whether chromium and molybdenum displace the FeS-MnS equilibrium at elevated temperatures (1300° C.) in the direction of FeS is not known. There is no reason for believing that the oxygen content of the steels was sufficient to remove all manganese as MnO.

An increase in carbon content to 0.56% in plain carbon steels does not improve the strength and ductility of 0.04-inch sheet at 900 to 1000° C. Most investigators state that an increase in carbon from 0.25 to 0.35% greatly increases the cracking difficulty in Cr-Mo steel. Werner explains this effect, which does not seem capable of ready explanation on the assumption of cracking at 900 to 1000° C., by assuming that the cracks occur during the transformation of austenite to other products at a little below the equilibrium temperature. Carbon tends to increase the stiffness of the steel at the transformation and promotes cracking. This explanation and Werner's effort to yoke sulphur and oxides with microcracking at about 650° C. completely lack experimental support.

The remarkable effect of special melting procedures in reducing cracking has not yet been absorbed into any theory. It seems that the special melting procedure involves choice of scrap and deoxidation, with, perhaps, some overheating of the melt. Deoxidation, if effective, removes oxides, but the total oxygen analyses reported by Bollenrath and Cornelius show no correlation with

welding crack sensitivity. Deoxidation may alter grain size characteristics, but nothing has been reported on the microstructure of the specially refined Cr-Mo steels.

Finally, it should be remembered that Brueggeman[81] did away with every trace of cracking in Cr-Mo tubing ($1^1/_2$ inches o.d., 0.020-inch wall) by switching from neutral flame to carburizing flux procedure, and Cornelius practically eliminated cracking by using metal arc instead of oxyacetylene welding. It is hard to reconcile Cornelius' belief that the smaller heat-affected zone reduced cracking in arc welding with Breuggeman's statement that there is little difference in welding speed between neutral flame and carburizing flux procedures. Possibly the fact that the base metal in the uncarburized state is never melted in the carburizing flux process may have some significance.

For the reader's convenience Table 46 has been prepared for ready reference.

Table 46—Causes of Cracks in Welded Cr-Mo Aircraft Sheet and Tubing

Increasing carbon content increases cracking (Müller, Zeyen, Werner).
Sulphur and phosphorus (possibly oxides) increase cracking (Müller) but to the contrary (Bollenrath and Cornelius). Oxides increase cracking (Bardenheuer and Bottenberg); to the contrary (Eilender and Pribyl).
Oxygen, hydrogen and nitrogen (in small amounts) have no effect (Bollenrath and Cornelius).
Cold stretching before welding increases cracking (Müller); doubtful (Bardenheuer and Bottenberg).
Normalizing or heat treating before welding has no effect (Müller, Eilender and Pribyl and Bollenrath and Cornelius); diffusion annealing has some effect (Eilender and Pribyl).
Special melting and deoxidizing procedures reduce cracking (Zeyen, Eilender and Pribyl, and Bollenrath and Cornelius).
Open-hearth scrap in the charge reduces crack sensitivity (Bollenrath and Cornelius); no effect (Eilender and Pribyl).
A slight compression stress in the jig may prevent cracking (Johnson).
Uniformity, absence of segregation is important (Eilender & Pribyl).
Large ingots promote crack sensitivity (Bollenrath and Cornelius).
Grain size is important (Bardenheuer & Bottenberg); to the contrary (Eilender & Pribyl).
Overheating in the steel furnace may reduce crack sensitivity (Bollenrath and Cornelius). Boiling is important in the furnace (Bardenheuer and Bottenberg).
Casting temperature has no effect (Bollenrath and Cornelius). Deoxidation with Al followed by Ca-Si is good (Eilender and Pribyl).
Crack sensitivity increases as thickness decreases (Clements, Werner, Bollenrath and Cornelius).
Martensite has some effect (Bardenheuer and Bottenberg); to the contrary (Scherer and Eilender and Pribyl).
Preheating to 100–200° C. reduces cracking (Bollenrath and Cornelius).
The welding process affects crack sensitivity (Bollenrath and Cornelius, Brueggeman, Seeman).
Copper coating on steel increases cracking (Phillips, Birdsall).
Overheating during welding causes cracks (Phillips).
Cracking increases as the tensile strength of the steel at room temperature increases (Clayton).

NOTE: Less well substantiated causes have been omitted from the Table.

Welding Procedure

Oxyacetylene Welding.—For the experienced welder and welding designer, Johnson's[87] instructions for oxyacetylene welding are basic. Low-carbon steel rod (0.06 C, 0.15 Mn, 0.06 Si) without flux is satisfactory for S. A. E. X4130. S. A. E. X4140 is not recommended for welding, but, if used, it should always be heat treated after welding. The most prolific source of weld failures is the neglect to melt the base metal (cold welds). In a joint between members of unequal section, the thicker section should be preheated. Excessive difference in thickness may result in burning the thin steel. The repeated application of heat on the small area in a cluster where all the members meet weakens the base metal. Not more than six members should converge at a cluster. Welding should be toward, rather than away from, edges in order to avoid edge cracking.

Most writers mention the poor welding quality of Cr-Mo steel filler rod. Streb and Kemper[99] observed that most rods containing 0.30 C, 0.52 Mn, 0.31 Si, 0.89 Cr, 0.21 Mo, 0.12 Cu produced a viscous slag and porous welds. Other rods of the same composition, however, behaved much better, perhaps because they had a high slag content. Baumgärtel[102] found that Cr-Mo rods (0.34 C, 0.55 Mn, 0.15 Si, 0.022 P, 0.02 S, 0.96 Cr, 0.27 Mo, 0.03 Cu) gave a gassy pool and a brown slag containing Fe, Mn, Cr and Mo. In Sisco and Boulton's[66] tests the Cr-Mo wire (uncoated, 0.28 C, 0.61 Mn, 1.14 Cr, 0.95 Mo) did not run through the junction properly. It may be noted that several writers mention the high-molybdenum rod but do not explain the purpose of the high molybdenum content. Zeyen[101] experienced difficulty only in the poor fluidity of his steel No. 4 (0.34 C, 0.20 Si, 0.63 Mn, 0.010 P, 0.010 S, 1.03 Cr, 0.28 Mo). His other Cr-Mo steel rods gave no trouble. The rod containing 2% Cr was excellent and mild steel was superior in running quality to dead soft iron. Kindelberger[106] found that a low-carbon rod (0.06 C) was easier to handle than a Cr-Mo rod. A French welder[124] recommended a silicon-manganese steel (no details) as filler rod for Cr-Mo tubing.

A test to demonstrate welding quality that was devised by the American Bureau of Welding's Committee on Welding Procedure was applied to Cr-Mo tubing by Whittemore and Brueggeman.[103] The pickled base metal is melted by oxyacetylene torch on the surface and end of the tube. Even melting without boiling signifies good welding quality. The flame adjustment must be exactly neutral, according to Sutton.[90] The Royal Aircraft Establishment[125] found that Cr-Mo steel was more difficult to weld than plain carbon or carbon-manganese aircraft steel. On the other hand, Dobson and Taylor[126] remarked upon the quiet pool obtained with Cr-Mo steel in oxyacetylene welding. Cr-Mo steel was believed superior in this respect to carbon-manganese aircraft steel. They recommend a rod containing 0.10 C, 0.60 Mn, 0.05 S, 0.05 P, 0.20 Ni, without flux and free from oxide, slag inclusions, rust and grease.

Detailed instructions for gas welding S. A. E. X4130 steel using the neutral flame technique have been supplied by a number of writers. Kindelberger[106] stated that the torch is usually held at an angle to the work. The total shrinkage allowance for a 1 x 0.049-inch tube fish mouth welded at each end is $^1/_8$ inch. For a 2 x 0.065-inch tube welded into an intricate fitting at each end the allowance is $^1/_4$ inch, the first weld being allowed to cool completely before the other end is welded. Bollenrath and Cornelius[118] emphasized the necessity for employing a strictly neutral flame with Cr-Mo steel. Excess oxygen creates blow-holes and spatter; excess acetylene causes carbon pick up with brittleness. Since it is difficult to maintain a neutral flame, a slight excess of oxygen may be tolerated, as George[127] suggested. Since the flame must be smaller than for unalloyed steel, the speed of welding is correspondingly slow. Hoffmann[128] believed that the purpose of the neutral flame was to prevent slagging of chromium.

In Birdsall's[121] instructions for oxyacetylene welding S. A. E. 4130 and X4130 with a neutral flame and unalloyed, low-carbon rod, it is stated that a rod $^1/_{16}$ inch diameter is suitable for sheet less than 0.115 inch thick. For plate 0.315 to 0.50 inch thick a $^5/_{32}$-inch rod is used.

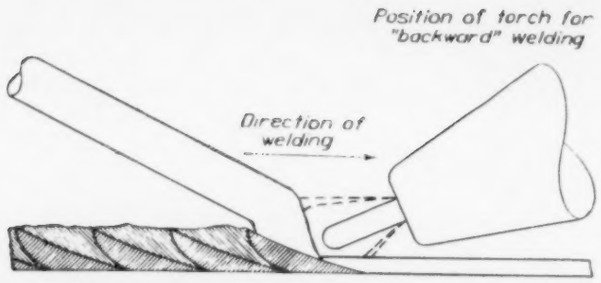

Fig. 12—Diagram of Bead Used in Making Carburizing Flux Welds in Thin-Walled Cr-Mo Steel Tubing, Showing How the Puddle Is Made to Solidify in Increments. Brueggeman[81]

Practically the same instructions are given to Phillips,[120] who is also in close agreement with Johnson. Each weld should be allowed to cool completely before another weld on the same part is begun. Tip sizes are 0.026-inch hole diameter for stock 0.015 to 0.031 inch thick; 0.055-inch hole diameter for stock 0.188 to 0.25 inch thick. Sand-blasted parts acquire a thin film of silica which make welding difficult. Welds should always be normalized at 870–930° C. Crack detection is made less tedious by cadmium plating. A French welder[85] illustrates several details of construction of oxyacetylene welded Cr-Mo aircraft parts (0.20–0.25 C, 0.80–1.10 Cr, 0.25 Mo, 0.40 Mn, 0.15 Si, 0.003 S and P).

The carburizing flux (Lindeweld) procedure for oxy-acetylene welding Cr-Mo steel was evolved, according to Anderson,[114] for the purpose of overcoming the decarburization that invariably resulted in neutral flame technique. To eliminate oxides, Anderson stated, the neutral flame welder must overheat the metal to secure fluidity, but in so doing the weld is decarburized. The carburizing flux process involves a special alloy steel rod having the same tensile strength as the thin walled tubing (S. A. E. 4130 and X4130) for which carburizing flux procedure is adapted. The torch is adjusted to give a carburizing flame. Backhand technique reduces the quenching effect and is called for particularly if the wall thickness is 0.065 inch or less. Experienced operators use a tip one size larger than usual and the torch is inclined to form a very acute angle with the seam. Welding rod is applied only after the carbonaceous film has been formed after which the torch is manipulated so that the film covers unmelted base metal in advance of the puddle. The heat effect may extend $^7/_8$ inch to each side of the weld (no details). The carburizing flux procedure may be used also in welding plain carbon steel to Cr-Mo steel.

In welding thin walled S. A. E. X4130 tubing (not sheet) Brueggeman[81] (see section on Mechanical Properties) found that the carburizing flux procedure was the only remedy for cracking. The luminous feather is 2 to $2^1/_2$ times the length of the inner cone. (Anderson recommended not more than $1^1/_2$ times the length of the inner cone.) The torch must be manipulated to confine the molten puddle to as small an area as possible, Fig. 12, so that the film of carburized metal of low melting point, which forms on the base metal heated in the carburizing flame, is not diluted by the relatively low-carbon filler rod (0.17 C, 1.02 Mn, 0.38 Si). Forehand technique is used if the wall thickness exceeds 0.030 inch.

Arc Welding.—The arc welding of S. A. E. X4130 is described by Jennings,[21] who did not have aircraft welding particularly in mind. Preheating to 150 to 260° C. (300 to 500° F.) avoids a brittle heat-affected zone. Shielded arc, carbon-molybdenum electrode (no details) arc recommended with procedure the same as for unalloyed steel. Stress annealing at 600 to 650° C. (1100 to 1200° F.) is desirable.

In 1926 Hird[66] (1926) applied arc welding with success to S. A. E. X4130 aircraft sheet and tubing. The tubing was $^3/_4$ to $1^1/_2$ inches diameter. A thin coated electrode (0.06 C, $^1/_{16}$ to $^3/_{32}$ inch diameter) and light holder were used, Table 47. It was necessary repeatedly

Table 47—Arc-Welding Conditions for S. A. E. X4130 Sheet and Tubing. Hird[66]

Gage of Sheet or Tubing	Amperes	Arc Voltage	Type of Weld
20, 21, 22	20	15	Bead
20, 21, 22	30	12	Fillet weld
17, 18	40	10	Bead
17, 18	50	8	Fillet weld

(Open-circuit voltage = 55)

to shorten the arc length in order to permit the globule of molten metal to be pulled off by surface tension. In this way the arc temperature is reduced and melting through is avoided. The current had to be increased 50% at the start of a weld in order to heat the base metal and secure good fusion. Arc welding created less distortion than oxyacetylene and was more convenient for jig welds.

Cornelius[79] has also employed arc welding with success in welding Cr-Mo aircraft sheet and tubing 0.04 to 0.12 inch thick (see sections on Mechanical Properties, Hardness and Cracking). Great skill is required even at low currents in order to obtain welds with uniform surface and penetration, and without porosity. Johnson,[87] too, emphasizes the importance of skillful welders. The arc bead is likely to be heavy and irregular. According to Green,[74] the deposit efficiency of a bare electrode containing 0.47 C, 0.59 Mn, 0.69 Cr, 0.37 Mo was exceptionally poor: 60% with electrode negative, 53% with electrode positive. The deposit efficiency is the ratio of the weight of the electrode consumed to the weight of the deposit made vertically downward on a steel stud $1^1/_4$ inches diameter.

Atomic Hydrogen Welding.—The atomic hydrogen welding of S. A. E. X4130 aircraft struts with a filler rod of the same analysis is quicker than oxyacetylene welding, according to Prentiss.[129] Bollenrath and Cornelius[84] (see section on cracking) found that atomic hydrogen welding decreased cracking in Cr-Mo tubing. They illustrate a number of electrode holders especially adapted to intricate joints and remark that the process is widely used in England and Italy for aircraft construction.

Bronze-Welding.—Bronze-welding of S. A. E. X4130 aircraft parts with a rod containing 60 Cu, 0.75 Mn, 0.15 Si, Zn remainder, according to Johnson,[87] produces less distortion of tubular members with thin walls than fusion welding but the joints have relatively low strength. Bronze-welding a welded joint is permissible. Daniels[107] (1928) recommended a rod containing 80 Cr, 20 Zn and a borax or boric acid flux for bronze-welding S. A. E. 4130. The joint should be cooled slowly to 540° C. (1000° F.) to avoid cracks. Brazed lugs on Cr-Mo aircraft steel (no details) withstood 122,400 cycles at 35,800 lb./in.^{2}, and 89,000 cycles at 40,400 lb./in.^{2} in Hackett's[4] alternating stress tests at 400 r.p.m. Downes[105] reported having no difficulty in bronze-welding Cr-Mo aircraft steel.

Resistance Welding.—The mechanical properties of spot welds in steel containing 0.25 C, 0.40 Si, 0.54 Mn, 0.62 Cr, 0.23 Mo, 0.002 S, 0.003 P (tensile strength—

Table 48—Mechanical Properties of Spot-Welded Cr-Mo Steel, 0.20 Inch Thick. Dussourd[130]

Specimen	Electrode Pressure, Lb.	Cooled Freely After Welding: Total Load to Fracture in Single Shear, Lb.	Cooled Freely After Welding: Load per Unit Area of Spot Measured After Rupture, Lb./In.²	Cooled Freely After Welding: Load per Unit Area of Spot Welding Electrode, Lb./In.²	Cooled Under Electrode Pressure After Welding: Total Load to Fracture in Single Shear, Lb.	Cooled Under Electrode Pressure After Welding: Load per Unit Area of Spot Measured After Rupture, Lb./In.²	Cooled Under Electrode Pressure After Welding: Load per Unit Area of Spot Welding Electrode, Lb./In.²
As-welded (68.5 kva.)	880	10,950	67,500	89,500	12,000	72,500	98,500
Reheated by 27.5 kva., then cooled freely	880	10,800	71,000	88,000	12,350	74,500	101,000
Reheated by 27.5 kva., cooled under electrode pressure	880	11,200	83,000	92,000	12,650	78,000	103,500
Annealed in furnace	880	....	55,500	....	....	....	....
As-welded (68.5 kva.)	970	....	....	....	10,550	74,000	86,000
Reheated by 36.7 kva., then cooled freely	970	....	....	....	14,300	89,000	117,000
Reheated by 50 kva., then cooled freely	970	....	....	....	12,650	87,000	103,500
Reheated before cooling was complete	970	....	....	....	11,500	81,500	94,000

93,000 lb./in.², elastic limit = 59,000 lb./in.², elongation = 22.2%, 0.20 inch thick) have been determined by Dussourd,[130] Table 48. The cross section of the spot welding electrodes was 0.122 sq. in., and the welding time was 1.2 seconds. The time of reheating was less than 1.2 sec. Using a Rockwell Brale indenter (150 kg. load), Dussourd found that the base metal was 180 Brinell, the weld was 370–380 Brinell, and the maximum hardness, 395–400 Brinell (C 42 Rockwell) occurred not in the weld but in the heat-affected periphery. Large martensitic grains were observed in the welded zone. The maximum hardness was reduced to 360 Brinell by reheating with 36.7 kva., and to 305 Brinell by reheating with 50 kva.

The results show that cooling the weld under electrode pressure is beneficial but reheating is hardly justified. Maintaining the pressure during cooling raised the cooling velocity.

The tensile strength and rotating bend fatigue limit of flash welded S. A. E. X4130 tubing 1 inch o.d., 1/16-inch wall, Table 49, were determined by Johnson.[87]

Table 49—Tensile and Fatigue Strengths of Flash-Welded Butt Joints in S. A. E. X4130 Tubing. Johnson[87]

Heat Treatment After Welding	Tensile Strength, Lb./In.² Unwelded: Tube	Tensile Strength, Lb./In.² Unwelded: Joint	Rotating Bend Fatigue Limit, Lb./In.² Unwelded: Tube	Rotating Bend Fatigue Limit, Lb./In.² Unwelded: Joint
None	90,000 to 95,000	100,000	41,000	24,000
Heated 30 min. at 510° C. (950° F.)	....	103,000	41,000	32,400

The joints were not machined, and had higher tensile strength and fatigue limit (8000 to 14,000 lb./in.² higher fatigue limit) than oxyacetylene butt welds in the same material. The high fatigue strength of the flash welds was believed to be related to the very narrow heat-affected zone which is hot worked when the welding pressure is applied, Fig. 7. Spot welding of S. A. E. X4130 requires automatic time control. According to deGanahl[89,131] (1936), resistance welding of S. A. E. X4130 is unsuccessful because cooling is too rapid, and the welds are brittle. Upon being heat treated, spot welds often fractured. However, a Russian investigator[132] observed that Cr-Mo aircraft steel was less difficult to spot weld than 18–8.

WELDING OTHER CHROMIUM-MOLYBDENUM STEELS

Two classes of chromium-molybdenum steels have been discussed in foregoing sections, namely: the 4–6 Cr, 1/2 Mo steels and the aircraft steels of S. A. E. 4130 type. There is practically no information on the welding of other chromium-molybdenum steels (not containing other alloying elements) than these. In the section on S. A. E. 4130 steels tests by Zeyen were summarized on steels of somewhat different analysis, deposit efficiencies of a bare electrode (0.47 C, 0.69 Cr, 0.37 Mo) by Green were mentioned, and several references were made to an oxyacetylene welding rod containing 0.28 C, 0.61 Mn, 1.14 Cr, 0.95 Mo (Sisco and Boulton).

In addition, Portevin[133] has pointed out that a filler rod that is used in France for high-grade oxyacetylene welds contains 0.10–0.15 C, 0.60–0.80 Mn, 0.20–0.30 Si, 0.40–0.50 Cu, 0.30–0.40 Cr, 0.10–0.15 Mo. Oxyacetylene butt welds in superheater tubes (0.15 C, 0.76 Mn, 0.31 Si, 0.71 Cr, 0.41 Mo) that were normalized, then held 2 hr. at 700° C. before welding were made by Czternasty,[134] Table 50, with a welding rod of the same analysis. A creep test at 500° C. for 50 hr. at a stress of 21,400 lb./in.² (about 90% of the creep strength of unwelded base metal) showed that none of the welds exceeded a creep rate of 10 x 10^{-4}% per hour. However,

Table 50—Mechanical Properties of Oxyacetylene Welded Superheater Tubes. Czternasty[134]

Heat Treatment	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Bend Angle, Degrees
As-welded	41,500	68,000	127
Normalized	44,000	79,500	157 (maximum possible)
A	39,700	85,000	157 (maximum possible)

A = Held at normalizing temperature (no details), then furnace cooled to 700° C., then air cooled.

the unwelded base metal exhibited less initial and permanent deformation than the welds. The microstructure of the normalized welds appeared to be a mixture of ferrite and sorbite. Welds made with a similar rod in boiler plate 0.59 inch thick, Table 51, had lower strength. The root of the V butt weld was deeply chipped out and reverse welded.

Short time creep tests (50 hr., 500° C.) of oxyacetylene and arc welds were made by Schottky and Ruttmann[153] in steels 3/4 inch thick containing 0.13–0.15 C, 0.17–0.36 Si, 0.31–0.71 Mn, 0.17 Cu, 0.76–0.88 Cr, 0.08–0.25 Ni, 0.32–0.48 Mo. Unless the welds were heated 2 hr. at 700° C., the welds had higher short time creep strength than base metal. Heating 500 hr. at 500° C. did not affect short time creep strength. Some properties of arc welds in a steel containing 0.14 C, 0.75 Mn, 0.1 Si

Table 51—Mechanical Properties of Oxyacetylene Welded Boiler Plate. Czternasty[134]

	Chemical Composition							Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Cold Bend Elongation, %	Notch Impact Value, Mkg./Cm.²
	C	Mn	Si	Mo	P	S	Cr				
Plate	0.16	0.75	0.18	0.12	0.048	0.031	0.016	...	...	..	..
Rod	0.15	0.45	0.42	0.46	0.017	0.021	0.77	...	...	..	..
Weld	0.10	0.45	0.37	0.42	0.017	0.028	0.70	36,000	63,000	39	14.6

0.45 Cr, 0.45 Mo, Table 52, were determined by Meunier and Rosenthal.[135] The bend ductility of the welds was quite low. Single-V butt welds made by Sommer[136] with a cored electrode 0.16 inch diameter, 150 amps. in

Table 52—Properties of Arc Welds in 0.45 Cr, 0.45 Mo Steel. Meunier and Rosenthal[135]

Specimen	Bend Angle, Degrees	Bend Elongation, %	Maximum Brinell Hardness	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 7 Diam.
Unwelded	180	45	160	60,000	79,500	23
Single-layer weld	100	13	240	..	..	..
Four-layer weld	180	28	200	..	..	..

steel 0.47 inch thick containing 0.17 C, 0.36 Si, 0.91 Mn, 0.42 Cr, 0.93 Mo had a tensile strength of 81,000 lb./in.² in the form of bars machined to 0.39 x 1.18 inches. Three of four specimens broke in the weld at an elongation of 7% in 1.18 inches. Fillet welds (cruciform specimens) had a strength of 54,000 to 66,000 lb./in.² based on throat area.

If Cr-Mo superheater tubes (0.11 C, 0.43 Mn, 0.22 Si, 0.93 Cr, 0.47 Mo, 0.03 P, 0.03 S, 1.30 inches o.d., 0.18-inch wall) are flash welded in the same way (2100 lb./in.² upset pressure) as plain carbon steel tubes, the bend angle is only 10 to 20° and only occasionally is a strong weld made, according to Czternasty.[137] The bend tests were made with grooved rollers (3.5 inches diameter at base of groove) and plunger (twice the tube diameter). The specimen was 12 inches long, filled with lead to prevent buckling, and placed on the rollers, the open distance between which was 5 times the tube diameter. The tensile specimens were 12 inches long, had plugged ends, and were not machined.

Normalizing above Ac_3 followed by heating 2 hr. at 700° C. and air cooling did not improve the properties of the tubes flash welded in the usual way to the extent that was desired. No matter what changes in feed, pressure and power were made, a line of oxide inclusions was found at the weld, which suggested that the oxide layer on Cr-Mo tubes is particularly adherent or infusible. However, if the welds were made under a protecting gas (no details) which prevented scaling of the steel during welding, there were no oxide inclusions in the weld and the mechanical properties, Table 53, were improved. The results are for four specimens each, the bend failures in the specimens welded in air originated at oxide inclusions. All tensile specimens failed outside the weld. The high upset pressure that was used in the best specimens did not produce unusually large fins. Tests showed that the creep strength (10^{-3}% per hr. between twenty-fifth and thirty-fifth hour, no details) of the welds made in the protecting gas at 500° C. was 21,400 to 22,800 lb./in.²

According to R. Smallman-Tew (private communication, May 1938) an electrode depositing metal containing

Table 53—Mechanical Properties of Flash-Welded Cr-Mo Superheater Tubes Using the Best Machine Setting. Czternasty[137]

Protecting Gas	Heat Treatment	Yield Strength, Lb./In.²	Tensile Strength., Lb./In.²	Bend Angle Degrees
No	A	28,000 to 32,000	66,500 to 74,000	180 (one specimen broke at 54°)
No	B	33,000 to 38,000	65,500 to 76,000	180 (cracks in one specimen)
Yes	B	40,000 to 45,000	72,000 to 83,000	180 (no cracks)

A—Normalized above Ac_3.
B—Normalized above Ac_3, heated 2 hr. at 700° C., air cooled.

0.10 C, 0.40 Mn, 0.90 Cr, 0.60 Mo is used in England for surfacing worn unalloyed steel rails. The hardness of the deposit is 300 Brinell, if the rail is not preheated, and 230 Brinell, if the rail is preheated to 250° C. Preheating is customary to avoid cracks in the heat-affected zone of the rail. Smallman-Tew also states that a flux covered electrode depositing metal containing 0.5 C, 0.4 Mn, 6.0 Cr, 4.0 Mo, Rockwell C 65, is used for repairing worn dies.

WELDING CHROMIUM-VANADIUM-MOLYBDENUM STEELS

Aside from a statement by Jonscher[138] that a Cr-Mo-V rod is used for rail surfacing, there is no information available.

WELDING NICKEL-CHROMIUM STEELS

Mechanical Properties

The mechanical properties of metal deposited by nickel-chromium steel rods for oxyacetylene welding have been determined by Stursberg[139] and Kleinefenn.[140] Stursberg used a rod containing 0.11 C, 0.48 Mn, 0.30 Si, 0.008 P, 0.019 S, 3.58 Ni, 0.71 Cr for V butt welding plain carbon steel plates 0.24 inch thick containing 0.35 C, 0.65 Mn. He was particularly interested in the effect of different oxygen-acetylene mixture ratios on welding with eight different plain carbon and low-alloy steel filler rods. His test specimens were unusual. The tensile specimen was machined to a thickness of 0.16 inch, 0.55 inch wide in the 0.59 inch parallel section. The welds made with the Cr-Ni rod had the highest tensile strength of any: 104,500 lb./in.² The highest tensile strength was attained in all rods at an oxygen-acetylene ratio of 0.9:1, tests being made at ratios of 0.8, 0.9, 0.95, 1.0, 1.1, 1.2, 1.4 and 1.6.

Bend tests were made on specimens 0.20 inch thick, gage length 0.59 inch, plunger diameter 0.59 inch. The maximum bend elongation (crack 0.02 inch wide) was 39% and occurred at a mixture ratio of 1.0. The notch impact specimen had the same dimensions as the stand-

ard German round-notch specimen but was only 0.16 inch wide, to accommodate the 0.24-inch plate. The notch was in weld-metal and extended from root to face of weld. Base metal had a notch impact value of 8.2 mkg./cm.^{2} The weld made by the Cr-Ni rod had 9.1 mkg./cm.^{2} at an oxygen:acetylene ratio of 1.1:1. Bend ductility and notch impact value rapidly decreased as excess acetylene was added to the mixture. Although maximum tensile strength was attained at a ratio of 0.9, the ductility and notch impact value were low. At a ratio of 0.8 the notch impact value was practically nil; at a ratio of 1.6 the value was 3 mkg./cm.^{2}

The hardness was closely related to the mixture ratio, Table 54. The highest ratio of tensile strength to Brinell hardness was 0.35 and occurred at a mixture ratio of 1.0. The hardness of base metal was 175–185 Brinell. As with all other rods, the weld-metal had the same hardness as plate when the flame contained 2% excess acetylene.

Table 54—Hardness and Carbon Content of an Oxyacetylene Weld Made with a Cr-Ni Rod as a Function of Mixture Ratio. Stursberg[139]

Mixture Ratio*	Carbon Content, % of a Deposit Made on a Plate Containing 0.35 C, 0.66 Mn, 0.19 Si	Brinell Hardness of Weld-Metal (Converted from Rockwell)
0.8	2.10	415
0.9	0.60	275
0.95	...	220
1.0	0.17	170
1.6	0.165	160

* Ratio of oxygen to acetylene by volume.

As shown in Tables 10 and 26 of the review of literature on the Effect of Nitrogen on the Welding of Steel, Kleinefenn oxyacetylene welded plates containing 2.5 Ni with a rod containing 0.15 C, 0.03 Si, 0.35 Mn, 3.50 Ni, 0.75 Cr, the weld containing 0.09 C, 0.03 Si, 0.24 Mn, 3.10 Ni, 0.68 Cr, 0.0239 O_2, 0.0053 N_2. In comparison with unalloyed rods and a 2% Ni rod, the Cr-Ni rod had excellent strength, ductility and notch impact value as-welded and after heat treatments designed to reveal any capacity for embrittlement that may have been present.

A thorough study of the hardness and notch impact value of the heat-affected zone of a plate (6 x 6 x $^5/_8$ inch, 0.29 C, 0.26 Mn, 3.25 Ni, 1.35 Cr, water quenched from above A_3, tempered 480° C., no martensite) on which single beads of heavy organic coated mild steel electrodes $^1/_8$, $^3/_{16}$ and $^5/_{16}$ inch diameter were deposited was made by Armstrong.[19] In one section one bead was deposited on top of the first bead and in other experiments the plate was preheated up to 680° C. (1250° F.) and removed from the furnace just before welding with $^5/_{32}$-inch electrodes. The penetration of the single beads into the plate was 0.0625 to 0.0938 inch in all tests and was not affected by size of electrode or by preheating. However, the hardness and depth of the heat-affected zone, Table 55, as revealed in the macro- and microstructure was closely related to these factors. The microstructure of the surface welded specimens showed that the heat-affected zone was martensite if the preheat was below 260° C. The specimen contained cracks if preheating was below 500° F. At 260° C. and above troostite and sorbite were found with martensite, which was present even in the specimen preheated to 680° C. An unwelded plate water quenched from 870° C. and drawn at 680° C. contained no martensite. The grain size of the heat-affected zone adjacent to the bead of weld-metal and was not affected by preheat. The maximum hardness in the heat-affected zone occurred a little beyond the fusion line because there was some dilution of base metal by unalloyed weld-metal. There was also some pick up of alloy by the weld-metal.

The Izod notch impact value of the surface welded specimens was determined by grinding off the weld bead and notching the heat-affected zone or unaffected area, Table 56. In some of the hard specimens the notch was ground. The results show that the heat-affected zone injures the Izod value of base metal, but preheating

Table 56—Izod Impact Value (Ft.-Lb.) of Surface Welded Cr-Ni Steel. Armstrong[19]

Electrode Diameter, Inch	Temperature of Plate, ° C.	A	B	C	D
$^1/_8$	2	43.0	33.0	61.0	52.0
$^3/_{16}$	2	39.0	40.0	60.0	51.0
$^5/_{16}$	2	31.5	52.0	58.0	50.0
$^5/_{32}$	100	35.0	35.0	59.0	53.0
$^5/_{32}$	200	27.0	..	31.0	29.0
$^5/_{32}$	260	23.0	..	32.0	28.0
$^5/_{32}$	375	25.0	..	33.5	29.0
$^5/_{32}$	540	23.0	..	36.0	30.0
$^5/_{32}$	680	21.0	..	35.5	31.0

A = Notched across weld.
B = Notched on opposite side from, but immediately below, the weld.
C = Notched in plate on the same side as the weld but in the unaffected area below the weld.
D = Notched in side of plate at 90° to weld in the unaffected area above the weld.

Table 55—Vickers Hardness and Depth of Heat-Affected Zone in Cr-Ni Steel as a Function of Electrode Size and Preheat Temperature. Armstrong[19]

Diameter of Electrode, Inch	Temperature of Plate, Deg. Cent.	Vickers Hardness				Depth of Heat Affected Zone, Inch
		Weld-Metal	Heat-Affected Zone	Unaffected Zone	Unwelded Plate	
$^1/_8$	Approximately 2	278 to 282	423 to 446	231 to 235	232*	0.0781
$^3/_{16}$	Approximately 2	243 to 249	423 to 487	233 to 246	514†	0.0938
$^5/_{16}$	Approximately 2	249 to 280	420 to 466	245 to 251	...	0.1094
Two layers	2	156 to 190	278 to 320	224 to 227	...	....
$^5/_{32}$	100	280 to 288	398 to 446	227 to 235	540	0.0938
$^5/_{32}$	200	233 to 237	368 to 434	229 to 235	477	0.1094
$^5/_{32}$	260	231 to 243	354 to 405	230 to 237	440	0.1250
$^5/_{32}$	375	207 to 211	256 to 368	224 to 233	445	0.1406
$^5/_{32}$	540	187 to 198	245 to 339	227 to 238	302	0.2031
$^5/_{32}$	680	203 to 205	192 to 333	215 to 229	237	0.2813

* As-rolled.
† Water quenched from 870° C.; remaining figures in this column are hardness of unwelded quenched plate after heating to the preheat temperature. The highest preheat temperature was above the critical temperature of base metal.

above 100° C. has a still greater effect in decreasing impact value and obscures any great effect due to welding.

Using an electrode 3/16 inch diameter containing 0.53 C, 0.85 Cr, 3.22 Ni, 0.76 Mn, 0.35 Si (weld-metal = 0.16 C, 0.58 Cr, 3.27 Ni, 0.58 Mn, 0.20 Si), Noderer[34,141] built up cones of weld-metal 1 inch high, 1 inch base, on cast steel containing 0.45 C, 0.84 Cr, 3.05 Ni, 0.80 Mn, 0.40 Si. The hardness of weld-metal was measured before and after being struck about 200 blows with a heavy ram. It was found to be immaterial whether the electrode was positive or negative, or was bare or sull, or lime coated. The Brinell hardness of the weld-metal varied from 302 to 380 in different cones and was increased 30 to 40 Brinell units in most tests by compression of about 30%. The deposits deformed too much to be of value in service as rail surfacing. The microstructure contained coarse grains and some free ferrite.

According to Hodge,[47] the heat-affected zone of arc welds in S. A. E. 3330 (3340) may be as high as 450 Brinell. In a multilayer weld, the hardness in one specimen was 260 Brinell in the center of the heat-affected zone, but was 450 adjacent to the last bead. Although the weld-metal contained martensite, the structure of the heat-affected zone was not made clear. With lower carbon content, namely, 0.1%, arc-welded steel containing 3% Ni, 0.8 Cr has high toughness, Roux[142] found (no details). Zschokke[152] found that a steel with 0.3 C, 2 Ni, 1 Cr welded with high-grade alloy electrodes (no details) had a tensile strength of 95,500 lb./in.² at 20° C., 75,000 lb./in.² at 450° C. In Lubovsky's[9] tests on welds in steel containing 0.47–0.55 C, 0.50–0.60 Mn, 0.10–0.20 Si, 1.50–1.75 Ni, 0.60–0.75 Cr made with a bare electrode of the same analysis, the weld-metal was C 50 Rockwell, the heat-affected zone was C 42, and unaffected base metal was C 10. Rapatz[143] explored the hardness in welded sheet containing 0.14 C, 0.8 Cr, 3.5 Ni, heat treated to 171,000 lb./in.² tensile strength. He used oxyacetylene welding and coated, cored and austenitic electrodes. However, important details are lacking and, since the maximum hardness reported was only 130 Brinell, his results seem to have extremely limited application.

Thermit Welding

A detailed study of the thermit welding of cast-steel guard rails containing 0.49 C, 0.58 Mn, 0.36 Si, 0.034 P, 0.034 S, 0.84 Cr, 3.20 Ni has been reported by Tinnon.[144] Welds made with rail thermit (no details) were 158 to 185 Brinell; welds made with thermit steel having the same composition as base metal were 273 to 302 Brinell. The heat-affected rail head reached 315 to 360 Brinell in these tests. If the welds were cooled in the mold with only the heads exposed, the heat-affected zone was 180 to 200 Brinell, which led to the conclusion that slow cooling is important. No cracks or flaws were found in any of the welds. The structure of the Cr-Ni thermit weld was coarser than the rail thermit weld.

Resistance Welding

The flash and resistance butt welding of nickel-chromium steels (for chains) has been studied by Galibourg and Ballay,[145] Table 57 (see section on Resistance Welding in review of literature on Welding Nickel Steels for details). The harder specimens of steels F, H and J were machined before heat treatment. Obviously the flash welds were superior to the resistance butt

Table 57—Mechanical Properties of Flash and Resistance Butt-Welded Cr-Ni Steels. Galibourg and Ballay[145]

Flash Welds

Steel	Composition	Treatment After Welding	Brinell Hardness	Static Tensile: Elastic Limit, Lb./In.²	Static Tensile: Tensile Strength, Lb./In.²	Static Tensile: Elongation, % in 4 In.	Reduction of Area, %	Impact: Impact Work Ft.-Lb.	Impact: Tensile Elongation, % in 1.4 Inches
F	0.10 C 3 Ni 0.6 Cr	Oil quenched from 850° C. Heated to 850° C., cooled in furnace	325 165	131,000 57,500	142,000 75,000	8.5 21.5	56 73	33 49	7.5 20
G	0.25 C 2.5 Ni 0.8 Cr	Oil quenched from 850° C., water quenched from 600° C. Heated to 850° C., cooled in furnace	294 197	125,000 66,500	140,000 104,000	10.8 11.8	42.5 43	45 43	10 14.5
H	0.35 C 3.75 Ni 1.5 Cr	Air quenched from 850° C., drawn at 300° C. Heated 30 min. at 650° C., cooled in furnace	440 208	194,000 82,500	228,000 110,000	8.0 17.3	46 58	20 8.7	4.5 2.1
I	0.30 C 2.5–2.8 Ni 0.6–0.8 Cr 0.25–0.35 Mo	Oil quenched from 850° C., air quenched from 625° C. Heated 30 min. at 650° C., cooled in furnace	290 230	126,000 80,500	133,000 106,000	15.3 16.6	69 67	44 30	15 12

Resistance Butt Welds

Steel	Static Tensile: Elastic Limit, Lb./In.²	Static Tensile: Tensile Strength, Lb./In.²	Static Tensile: Elongation % in 4 Inches	Reduction of Area, %	Impact Tensile: Impact Work, Ft.-Lb.	Impact Tensile: Elongation, % in 1.4 Inches	Number of Tests
F	123,000	123,000	2.3	1.5	20	4.7	2
	56,000	71,500	8.3	9	43	17.5	1
G	116,000	116,000	0.4	0	20	5.5	2
	68,000	93,500	4.9	0	..	..	1
H	154,000	154,000	0	0	9.4	1.4	2
	88,000	88,000	2.1	..	54	12.5	1
I	120,000	120,000	0.4	0	37	12	1*
	74,500	104,000	5.5	10	26	10.5	1

* 1 flash welded static tensile specimen had 4.2% elongation, 60% reduction of area; 1 resistance butt-welded impact tensile specimen had 1.2% elongation, 3 ft.-lb.

welds which contained a row of peculiar cavities in the upset zone a short distance back of the weld, especially in steel I. There was considerable difficulty with cracks. Quenching from above the critical range after welding resulted in high static and impact tensile strength in all the flash welds. It is not clear what part, if any, was played by temper brittleness. Flash welds in steel I appeared to contain martensite (× 150) in the middle of the weld with a zone of grain refinement on both sides.

Standard tension specimens machined from resistance butt welds in bars 1 inch diameter containing 0.30–0.35 C, 0.60–0.70 Mn, 0.1–0.2 Si, 1.20–1.50 Ni, 0.35–0.50 Cr, were heat-treated (no details) and tested by Boyd,[146] Table 58. The strengths of the annealed and water quenched welds are unusually low for Cr-Ni steel.

Table 58—Tensile Properties of Resistance Butt-Welded Ni-Cr Steel. Boyd[146]

	Un-welded	As-Welded	An-nealed	Water Quenched
Elastic limit, lb/in.²	62,500	48,250	25,000	60,500
Tensile strength, lb/in.²	73,250	70,000	55,750	80,875
Elongation, % in 2 inches	17	20	35	23
Reduction of area, %	57	61.5	66	66

Flame Cutting

Wiss[42] found that the heat-affected zone in oxyacetylene flame cut armor plate containing 0.35 C, 3.2 Ni, 1.7 Cr was 0.28 and 0.16 inch deep in steels 16 and 1.58 inches deep, respectively. The surface had good machinability. Wiss believed that deep hardening steels have the deepest heat-affected zone in flame cutting and that the hardness of the flame cut surface of alloy steels generally is no greater than that of unalloyed steel of the same carbon content. The depth depends on thermal conductivity, critical temperatures, speed of cutting, size of torch, thickness and surrounding atmosphere. Wiss[41] found that the nickel content of the flame cut surface is higher than base metal, Table 59.

Table 59—Composition of Flame Cut Edge of Cr-Ni Steel. Wiss[41]

	C	Mn	Si	Cu	Ni	Cr
Base metal	0.3	0.29	0.06	0.1	3.2	1.7
Flame cut edge	about 0.5	0.28	0.04	0.25	4.3	1.4

Machine flame cutting was not difficult in de Jessey's[43] experiments with a steel 1 inch thick containing 0.63 C, 0.32 Si, 0.92 Mn, 20.72 Ni, 2.16 Cr. There was no drag at speeds up to 55 ft./hr., but 1/4-inch drag at 75 ft./hr. The cuts made at speeds of 35–55 ft./hr. were smooth.

Rockwell hardness—depth curves for flame hardened forged steel shafts 3.86 inches diameter were determined by Zorn,[112] Table 60. The shafts rotated at a surface speed of 6.1 inches per minute. In the higher alloy steels an increase in gas consumption beyond a critical value does not increase the hardness.

Recovery

Complete recovery of nickel from a bare Cr-Ni steel electrode was reported by Noderer.[34,141] The electrode contained 0.53 C, 0.85 Cr, 3.22 Ni, 0.76 Mn, 0.35 Si; weld-metal contained 0.16 C, 0.58 Cr, 3.27 Ni, 0.58 Mn, 0.20 Si.

Chromium and nickel have a mutual beneficial effect on recovery from a coated mild steel electrode, according to Losana and Jarach,[33] Table 61 (see section on Welding Chromium Steels and Table 24 of review of literature on Welding Nickel Steels for details). An increase in nickel in the coating improved the recovery of chromium, and an increase in chromium in the coating improved the recovery of nickel. An increase in manganese had no effect, but an increase in carbon slightly improved the recovery of chromium.

Table 60—Flame Hardening of Cr-Ni Steels as a Function of Oxygen Consumption. Zorn[112]

Composition of Steel					Rockwell C Hardness		Depth in Inches at which 40 C Rockwell Was Reached			
C	Mn	Si	Cr	Ni	Base Metal	Flame Hardened (Maximum)	163 Ft.³/Hr.	141 Ft.³/Hr.	124 Ft.³/Hr.	103 Ft.³/Hr.
0.28	0.62	0.29	0.56	1.57	10	53	0.122	0.110	0.059	0.035
0.34	0.52	0.32	0.79	2.35	10	51	0.098	0.083	0.071	0.047
0.33	0.48	0.30	1.14	4.32	25	55	0.102	0.094	0.087	0.039

Table 61—Recovery of Nickel and Chromium from Coated Mild Steel Electrodes. Losana and Jarach[33]

No.	(Mn)	(Si)	(Ni)	(Ni)¹	(Cr)	(Cr)¹	(C)	[Nn]	[Ni]	[Ni]/(Ni)¹	[Cr]	[Cr]/(Cr)¹	[C]	Brinell Hardness
1	7.12	2.50	7.10	2.8	4.02	1.6	2.54	0.17	0.98	0.35	0.36	0.23	0.05	170
2	7.06	2.44	13.94	5.5	4.18	1.7	2.38	0.18	3.58	0.65	0.59	0.35	0.07	282
3	7.21	2.36	28.84	11.4	4.32	1.7	2.41	0.18	5.15	0.45	0.87	0.51	0.09	310
4	7.00	2.51	7.47	3.0	8.26	3.3	2.30	0.26	2.51	0.84	1.96	0.59	0.11	302
5	6.94	2.30	13.40	5.3	7.94	3.1	2.63	0.38	5.02	0.95	2.38	0.77	0.15	430
6	6.81	2.63	28.62	11.3	8.32	3.3	2.42	0.21	10.84	0.96	3.12	0.95	0.18	500
7	7.32	2.43	7.31	2.9	17.10	6.8	2.26	0.42	3.02	1+	2.51	0.37	0.23	470
8	6.92	2.60	13.57	5.4	16.86	6.7	2.40	0.45	6.88	1+	3.24	0.48	0.25	500
9	7.14	2.37	28.34	11.2	16.70	6.6	2.31	0.37	12.92	1+	4.29	0.65	0.29	500
10	13.82	2.16	7.08	2.8	4.26	1.7	5.40	0.72	1.88	0.67	0.84	0.50	0.10	...
11	13.74	2.38	13.34	5.3	4.31	1.7	5.16	0.69	3.76	0.71	1.23	0.73	0.17	...
12	13.21	2.42	27.98	11.1	4.09	1.6	5.53	0.65	6.35	0.57	1.61	1+	0.24	500
13	13.17	2.34	7.13	2.8	8.16	3.2	10.39	0.63	3.02	1+	2.02	0.63	0.21	462
14	13.60	2.18	14.02	5.6	8.46	3.4	10.21	0.60	6.15	1+	2.46	0.72	0.23	500
15	13.43	2.41	27.85	11.0	7.98	3.2	10.54	0.55	10.98	1	3.34	1+	0.26	500

( ) = Weight % constituent in coating.
[ ] = Weight % constituent in deposit.
( )¹ = Percentage of nickel or chromium calculated on basis of core rod of electrode.
[ ]/( )¹ = Approximate recovery.

General Observations

In Harris'[18] opinion high strength nickel-chromium steels require heat treatment after welding because they cannot resist the internal stresses resulting from austenite transformation at relatively low temperatures (no details). According to Hatfield,[16] steels with 3% Ni, 1.5% Cr have still greater air hardening capacity than straight nickel steels, and heat treatment is always advisable after welding. As pointed out by R. Smallman-Tew most of the welding on these high-alloy steels is for the purpose of repair and the results, even in the forced absence of heat treatment, have been satisfactory.

In welding heat-treated nickel-chromium steel Stanner[147] found that beads should never be deposited adjacent to each other. The weld should not be quenched in oil or water (no details). Sage[148] recommended a rod containing 0.30–0.40 C, 0.50–0.80 Mn, 0.50–0.75 Cr, 1.00–1.50 Ni, 0.20 Si for building up plain carbon steel plow points. A number of instances of successful welding repairs on chromium nickel steel front axles have been reported[149] by skillful and patient welders. Portevin[150] recommends 18–8 electrodes for welding Ni-Cr and similar "self-hardening" steels.

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SUGGESTED RESEARCH PROBLEMS

1. The creep characteristics of welded 4–6 Cr steel with different alloying elements, such as titanium columbium, molybdenum and tungsten, and with different heat treatments. What is the effect of multilayer welding, and is the required reinforcement with plain carbon steel rods calculable from the results of creep tests?

2. What is the composition of the material blown from the kerf of flame cut plain chromium and chromium alloy steels? Has chromium any effect in increasing pick up of carbon from the oxyacetylene flame?

3. What rôle does chromium play in the arc between steel electrodes containing chromium?

4. The significance of temper brittleness in welding is not clear. If a steel that is subject to temper brittleness is welded, is a section of the heat-affected zone embrittled? Is the heating and cooling cycle during different types of welds in chromium alloy steels of different thicknesses of the sort to create temper brittleness during slow cooling after heating to the stress-relieving temperature? If so, what remedies are available?

5. If metallurgical treatment is not possible in welded high-tensile steels and such treatment is necessary to prevent air hardening or other embrittling tendencies, special steels will have to be evolved in which these tendencies do not exist. (Suggested by R. Smallman-Tew.)

6. The fact should never be lost sight of that a welded connection is infinitely more efficient than a riveted one, and if special steels are required to give the requisite strength in a riveted structure, the same strength and efficiency can be obtained in a welded structure using materials of simpler type. The present vogue for alloy steels is based on past experience with riveted work, and it is dangerous and detrimental to welding to insist on the use of complicated and unsuitable steels to satisfy this old fetish. This is one of the principal factors on which research work is required. (Suggested by R. Smallman-Tew.)

7. Does a small amount of chromium (0.50%) affect the machine setting for spot welding?

8. What factors (high melting point of chromium oxide, high heat of formation of chromium oxide, effect of coating constituents and flame adjustment) govern the recovery of chromium from welding rods of 4–6 Cr steel and other chromium steels? To what extent does plain carbon steel weld-metal pick up chromium from chromium steel base metal and to what extent does pick up depend on welding process and technique?

9. Can the alloying additions that are added to 4–6 Cr steel to prevent excessive air hardening be added to nickel chromium steels ($3^1/_2$ Ni, $1^1/_4$ Cr) with the same success, thus overcoming some of the welding difficulty?

10. What is the effect of increasing chromium content (up to 6%) on the maximum grain size of the austenite in the heat-affected zone during the deposition of a bead of weld-metal under controlled conditions of velocity (heat input) and taking into consideration the decrease of thermal conductivity with increasing chromium content?

Flame Cutting Nickel Steels

COMMENTING on the review of literature on Welding Nickel Steels (May 1938 Research Supplement). L. de Jessey, Paris, drew attention to his machine cutting experiments on steels 1 inch thick summarized in the accompanying Table.

The cutting orifice was 0.06 inch diameter and there were 5 preheating jets. It was found that it was necessary to intensify the preheat to cut the nickel steels compared with unalloyed, low-carbon steel. The acetylene consumption appeared to increase as the thermal conductivity of the steel decreased. The cut made at 35 ft./hr. and 18 cu. ft. acetylene per hr. in the 34% Ni steel was as smooth as cuts made at the same velocity in plain carbon steel. The depth of the zone in which the microstructure was altered by the cutting heat was 0.06 inch in the plain carbon steel (10 cu. ft. acetylene

Machine Flame Cutting of Nickel Steel

Composition of Steel				Speed of Cut,	Acetylene Consumption	Drag,
C	Si	Mn	Ni	Ft./Hr.	Cu. Ft./Hr.	Inch
0.09	0.3	0.49	1.87	30	10	0.06
				75	10	0.43
0.31	0.38	0.49	2.17	25	10	0
				75	11	0.51
0.13	0.29	0.39	5.20	25	11	0
				75	11	0.47
0.10	0.35	0.53	6.19	25	11–14	0
				75	10–14	0.43
0.24	0.29	0.91	33.76	35	16–18	0
				75	18	0.32
0.20	0.15	0.70	...	25	4–10	0
				75	4	0.28

per hr.), 0.08 inch in the 6% Ni steel (10 cu. ft. acetylene per hr.), but only 0.008 inch in the 33% Ni steel (18 cu. ft. per hr.), the cutting speed being about 40 ft./hr.

The use of nickel steel filler rods ($1^1/_2$ and $3^1/_2$% Ni) for multilayer butt welds in pipe $^3/_4$ inch thick was described by R. M. Rooke and F. C. Saacke (AMERICAN WELDING SOCIETY JOURNAL, **15** (10) 2-7 (1937)).

Effect of Nitrogen on Welding of Steel

In the review of literature on the Effect of Nitrogen on the Welding of Steel April 1938 Research Supplement (references 26 and 42) the following reference to the work of A. M. Portevin and D. Séférian was inadvertently omitted: *Rev. Metallurgie*, **33,** 705–720, (1936); **34,** 225–237 (1937).

DISTORTIONS AND/OR FAILURES DUE TO WELDING

To Representatives of the Welding Industry,

The Fundamental and Industrial Research Divisions are endeavoring to compile all the thoroughly useful information available on typical difficulties and problems due to *distortion and stresses caused by welding*. If possible, the Committee would like to have these problems accompanied by the solution which you have found to be desirable. If a solution has not been found it should be so indicated.

The general idea is that we will assemble this information, collate it, and, perhaps, arrive at fundamental truths, or at least be able to clearly indicate problems that need further study.

A questionnaire sent out is reproduced below.

ENGINEERING FOUNDATION—
WELDING RESEARCH COMMITTEE
FUNDAMENTAL RESEARCH
DIVISION

Questionnaire—Distortions and/or Failures Due to Welding

NOTE: Please Check or List

1. In your work have you encountered any difficulties due to:
( ) (a) Distortion during application of welding heat
( ) (*b*) Distortion during cooling after removal of source of welding heat
( ) (*c*) Cracking during application of welding heat
( ) (*d*) Cracking during cooling after removal of source of welding heat
( ) (*e*) Cracking in service
2. If so, please attach information (dimensions and sketch or photograph) on location of crack or cracks, size of cracks, appearance of cracks, and indicate here whether or not the problem was solved.
3. What process of welding was used?
.....
4. If a solution was found, were the difficulties overcome by:
( ) (*a*) Sequence of operations
( ) (*b*) Stress relieving (time and temperature and rate of cooling)
( ) (*c*) Preheating
( ) (*d*) Slow cooling
( ) (*e*) Peening
(*f*) Other ways.....
.....
5. Was the difficulty caused, in your opinion, by one of the following:
( ) (*a*) Joint design—rigidity of work
( ) (*b*) Composition, physical properties and quality of base metal
( ) (*c*) Weather conditions
( ) (*d*) Brittleness of the weld-metal
( ) (*e*) Stress concentrations
( ) (*f*) Welding technique
( ) (*g*) Improper sequence of operations
(*h*) List other causes.....
.....
Name .....
Address .....

Sample Replies

One public utility states:

"When field welding of carbon-molybdenum piping started at the No. 2 station of the Company, the joints were preheated to 500° F. with an oxyacetylene torch, the welding started, and if the joint was not completed that day, the same operation was performed the following morning. The joint was stress relieved as soon as the welding was finished. With this procedure the joint became cold at least once, and because of unavoidable interference with the welders due to other construction operations, some of the joints became cold several times before they were finished.

"X-ray examination of joints made in this manner showed a considerable number of joints to be defective because of cracks near the bottom of the weld. These apparently were the result of stress concentration caused by the cooling and reheating of the joints.

"The welding procedure was then changed to a continuous operation from the time of preheating the joint to its final stress relieving. Although this was considerably more expensive because of labor working overtime, it did practically eliminate the rejection and repair of welds because of cracks.

"We therefore deem it necessary either to weld carbon-molybdenum piping continuously or to use an induction heating arrangement on each side of the joint to prevent the temperature dropping below 500° F. at any time before the weld is finished. With this apparatus the joint can be preheated and the welding carried on in regular working hours with the desired temperature being maintained automatically overnight. The same apparatus is used for stress relieving also."

That this is not an unusual experience can be seen from the reply received from a large tank company.

"Many times we have found that an arc struck on a cold plate will result in cracks. The tendency to crack is increased if the arc is struck not only on cold metal, but on a partially welded seam which, upon cooling, had locked-up stresses in the adjacent metal. These cracks can readily be avoided by a little preheating.

"It is not unusual for cracks to develop in the weld-metal of partly welded butt seams if the welding is stopped before the joint has been completely welded. These cracks occur most frequently when the joint is to unite two members which, because of previous attachment to adjacent parts, are prevented from moving freely as the weld-metal cools. It is not difficult to see that, under such conditions, when only a few of many weld layers required for the finished joint have been laid and allowed to cool, the strain must, because of the much greater strength of the members being joined, take place almost entirely in the metal, and causes failures if the weld-metal is forced to stretch more than it can withstand.

"The obvious remedy is to either design so that there is no restraint, or to complete the seam welding in one continuous operation without allowing the weld-metal to cool.

"It has been our experience that a joint in mild steel which cools without cracking will almost always withstand tests usually made prior to service, and that a joint which withstands the tests will not fail during its service life. In the last seven years we have welded over 1200 tanks of 5000 barrels or large capacity, and none of them have failed in service, although several developed cracks during welding, or under test."